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RTO-MP-073

NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION

BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

RTO MEETING PROCEEDINGS 73

Future Modelling and Simulation Challenges

(Défis futurs pour la modélisation et la simulation)

Papers presented at the RTO NATO Modelling and Simulation Group (NMSG) Conference held in Breda, Netherlands, 12-14 November 2001.

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The Research and Technology Organisation (RTO) of NATO

RTO is the single focus in NATO for Defence Research and Technology activities. Its mission is to conduct and promote cooperative research and information exchange. The objective is to support the development and effective use of national defence research and technology and to meet the military needs of the Alliance, to maintain a technological lead, and to provide advice to NATO and national decision makers. The RTO performs its mission with the support of an extensive network of national experts. It also ensures effective coordination with other NATO bodies involved in R&T activities.

RTO reports both to the Military Committee of NATO and to the Conference of National Armament Directors. It comprises a Research and Technology Board (RTB) as the highest level of national representation and the Research and Technology Agency (RTA), a dedicated staff with its headquarters in Neuilly, near Paris, France. In order to facilitate contacts with the military users and other NATO activities, a small part of the RTA staff is located in NATO Headquarters in Brussels. The Brussels staff also coordinates RTO's cooperation with nations in Middle and Eastern Europe, to which RTO attaches particular importance especially as working together in the field of research is one of the more promising areas of initial cooperation.

The total spectrum of R&T activities is covered by the following 7 bodies:

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS Studies, Analysis and Simulation Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These bodies are made up of national representatives as well as generally recognised 'world class' scientists. They also provide a communication link to military users and other NATO bodies. RTO's scientific and technological work is carried out by Technical Teams, created for specific activities and with a specific duration. Such Technical Teams can organise workshops, symposia, field trials, lecture series and training courses. An important function of these Technical Teams is to ensure the continuity of the expert networks.

RTO builds upon earlier cooperation in defence research and technology as set-up under the Advisory Group for Aerospace Research and Development (AGARD) and the Defence Research Group (DRG). AGARD and the DRG share common roots in that they were both established at the initiative of Dr Theodore von Kármán, a leading aerospace scientist, who early on recognised the importance of scientific support for the Allied Armed Forces. RTO is capitalising on these common roots in order to provide the Alliance and the NATO nations with a strong scientific and technological basis that will guarantee a solid base for the future.

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Future Modelling and Simulation Challenges

(RTO MP-073 / NMSG-010)

Executive Summary

The 3rd NATO Modelling and Simulation (M&S) Conference was organised by the NMSG and hosted by The Netherlands, at the Royal Netherlands Military Academy in Breda (12 to 14 November 2001).

The specific topics highlighted in the Calling Notice for the Conference were as follows:

- Future trends and limits in M&S:
  - Gaming Industry and NATO needs,
  - Incorporating the human element into M&S.
- M&S best practice and policy:
  - Standards and architecture,
  - Integration of M&S systems to C3I systems,
  - Verification, Validation and Accreditation (VV&A) of M&S systems.
- Support to Operations, Exercising and Training:
  - Decision Support,
  - Campaign Planning and Mission Rehearsal.

More than 60 abstracts were proposed to the Conference Programme Committee, which was constrained to select only 24 Papers. The general level of Papers presented was judged overall good, even though this NATO M&S Conference was probably not of such a high standard as in previous NMSG M&S Conferences. The Conference was organised in four sessions by a grouping of Papers in the following themes in order to facilitate and generate discussions on common concerns:

- M&S Organisations, Perspectives and Policy
- Support to Operations:
  - Training at all Levels,
  - Communication systems and M&S.
- Future trends:
  - Virtual Forces and Artificial Intelligence,
  - Gaming and Agent Technologies,
  - Long Term Previsions and Perspectives.
- M&S best practices:
  - VV&A,
  - Standards.

The proceedings contain a technical evaluation of the Conference, copies of published papers and PowerPoint presentations.

Key outcomes and conclusions from the Conference:

a. The modelling of human behaviour is considered as a priority research area for the M&S community. This is an extremely difficult and challenging area. Whilst there is much that is still required to be achieved in this area, it is apparent that real progress has been made.

b. New NATO member nations and invited PfP nations are showing interesting progress in their approach to national M&S activities. It is recommended that the PfP should be considered as full partners of the NMSG community and be given the opportunity and encouraged to participate more often in a wider range of RTO technical activities.

c. The topic of Verification, Validation and Accreditation of simulation is always considered as an important part of any M&S Conference. The Papers presented at the 2001 NMSG Conference were of variable quality and interest, but they raised the largest degree of discussion. The effort made by the NMSG to address this topic should be increased in future years.

d. It was the first time that applications of the gaming industry have been presented in a NATO M&S Group Conference. Interesting presentations on new technologies and the use of gaming for education and training clearly demonstrated that a greater degree of interest should be given to this topic in the future.

Défis futurs pour la modélisation et la simulation

(RTO MP-073 / NMSG-010)

Synthèse

La 3ème Conférence OTAN sur la Modélisation et la Simulation (M&S) a été organisée par le groupe NMSG, aux Pays-Bas, à l'Académie Militaire Royale des Pays-Bas à Breda, du 12 au 14 novembre 2001.

Les sujets précisés dans l'appel à communications furent les suivants :

- Tendances futures et limites de la M&S :
  - L'industrie de la simulation et les besoins de l'OTAN,
  - L'intégration de l'élément humain dans la M&S.
- Politique et meilleures pratiques en matière de M&S :
  - Normes et architectures,
  - Intégration des systèmes M&S dans les systèmes C3I,
  - Vérification, validation et certification (VV&A) des systèmes M&S.
- Soutien aux opérations, aux exercices et à l'entraînement :
  - Soutien à la prise de décisions,
  - Planification d'opérations et préparation de mission.

Plus de 60 propositions de communications ont été reçues au Comité du programme de la réunion, qui s'est vu obligé de n'en choisir que 24. Le niveau général des communications présentées a été dans l'ensemble très satisfaisant, même si cette conférence M&S de l'OTAN n'a probablement pas atteint le même niveau d'excellence que les précédentes. La conférence a été organisée en quatre sessions qui regroupaient les communications sous les catégories suivantes, afin d'encourager des discussions sur des questions d'intérêt commun :

- Organisations, perspectives et politiques M&S,
- Soutien aux opérations :
  - Entraînement à tous les niveaux,
  - Systèmes de communication et M&S.
- Tendances futures :
  - Forces virtuelles et intelligence artificielle,
  - Technologies de simulation,
  - Prévisions et perspectives à long terme.
- Meilleures pratiques M&S :
  - VV&A,
  - Normes.

Le compte rendu contient une évaluation technique de la conférence, des copies des communications publiées et des présentations PowerPoint.

Résultats clés et conclusions de la conférence :

a. La modélisation du comportement humain est considérée comme un domaine de recherche prioritaire pour les spécialistes de la M&S. Il s'agit d'un domaine stimulant mais extrêmement difficile. Bien qu'il reste beaucoup de choses à faire dans ce domaine, il apparaît clairement que de réels progrès ont été réalisés.

b. Les nouveaux pays membres de l'OTAN et les pays du PfP invités ont annoncé des progrès intéressants en ce qui concerne la gestion de leurs programmes M&S nationaux. Les pays du PfP devraient être considérés comme des partenaires à part entière de la communauté NMSG. Ils

devraient avoir la possibilité, et être encouragés à participer plus souvent à un plus grand éventail d'activités techniques RTO.

c. Le sujet de la vérification, la validation et la certification de la simulation demeure un élément constitutif important de toute conférence M&S. Bien que la qualité et l'intérêt des communications présentées lors de la conférence NMSG 2001 fussent variables, elles ont donné lieu aux plus vives discussions. Les efforts consentis par le NMSG vis à vis de ce sujet devraient être accrus dans les années à venir.

d. La conférence a fourni l'occasion de présenter, pour la première fois, les applications de l'industrie de la simulation dans un cadre M&S de l'OTAN. Il a été démontré par les nombreuses communications intéressantes qui ont été présentées sur les nouvelles technologies et sur l'utilisation de la simulation aux fins de l'éducation et de l'entraînement, qu'il serait juste d'accorder plus d'importance à ce sujet à l'avenir.

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Technical Evaluation Report

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The 3rd **NATO Modelling and Simulation conference** was organised by the NMSG and hosted by The Netherlands, at the Royal Netherlands Military Academy in Breda (November 2001).

More than 60 abstracts were proposed to the conference Programme Committee, which was constrained to select only 24 papers. Main criteria considered for the selection were the following, listed by priority order:

- The interest and importance of the related topic for NATO,
- The relevance to the conference main themes,
- The requirement to have a fair and balanced participation between nations.

The conference was organised in four sessions by a grouping of papers in the following themes in order to facilitate and generate discussions on common concerns:

- M&S Organisations, Perspectives and Policy
- Support to Operations:
    - Training at all Levels,
    - Communication systems and M&S.
- Future trends:
    - Virtual Forces and Artificial Intelligence,
    - Gaming and Agent Technologies,
    - Long Term Previsions and Perspectives.
- M&S best practices:
    - VV&A,
    - Standards.

The general level of the selected papers was judged overall as good even though this NATO M&S conference was probably not of such a high standard as in previous NMSG M&S Conferences.

General assessment

It is sometimes difficult to assess some papers and presentations from a purely technical point of view: technical contents were rather variable and, in some papers non-existent. Nevertheless some papers provided information on progress made by PfP nations in their quest to acquire a satisfactory level of organisation and capabilities in the M&S area. In contrast to those informative papers, some papers were so theoretical or specific that few people were immediately able to evaluate the underlying content and the messages the authors wished to deliver.

The personal feeling of the author of this synthesis, and the general opinion of many attendees of the conference, is that the M&S community is still making significant progress. However, much still remains to be achieved before M&S may be considered as a mature technology within NATO, but there is no reason at this stage to be pessimistic.

Key outcomes and conclusions from the Conference were:

a. The modelling of human behaviour is considered as a priority research area for the M&S community. This is an extremely difficult and challenging area. Whilst there is much that is still required to be achieved in this area, it seems that real progress has been made.

b. New NATO member nations and invited PfP nations are showing interesting progress in their approach to national M&S activities. It is recommended that the PfP should be considered as full partners of the NMSG community and able to participate more often in all RTO technical activities and not only conferences and tutorials.

c. The topic of Verification, Validation and Accreditation of simulation is always considered as an important part of any M&S conference. Papers presented at the 2001 NMSG conference were of variable quality and interest, but they raised the largest degree of discussion. The effort made by the NMSG to address this topic should be increased in future years.

d. It was the first time that applications of the gaming industry have been presented in a NATO M&S Group conference. Interesting presentations on new technologies and the use of gaming for education and training clearly demonstrated that a greater degree interest should be given to this topic in the future.

Opening session:

Royal Military Academy welcoming address

Maj. Gen. C. G. J. HILDERINK, Royal Military Academy, THE NETHERLANDS

The director of the Royal Military Academy delivered a very short but informative introduction, perfectly fitting the general atmosphere of the conference. Major-General HILDERINK first provided some historic background about Breda, then, he briefly described the difficult but exciting tasks that have to be accomplished in the Academy. He concluded his presentation by briefly describing the organisation of the Academy.

Host Nation welcoming address

Maj. Gen. R. P. F. SEIJN, RNL Army, THE NETHERLANDS

The title of the presentation was "A more effective and efficient use of M&S simulation technology for the Royal Netherlands Army (RNLA)”. The policy of the RNLA is based on standardisation, re-use and interoperability of M&S. This policy is inspired from lessons learned from past errors. Generally speaking, the RNLA distinguish three domains of application: Training, Procurement and Operational use. The speaker emphasised the importance of international co-operation within the M&S community, in particular within NATO and the Western European Union.

NATO Keynote address

LTG W. S. WALLACE, Commander, US Army V Corps, Heildelberg

The General expressed his confidence on the real value of M&S for NATO training. He defined himself as an "abuser" of M&S and not a simple "user"! In fact, the audience respected the views of somebody having a real and long experience with simulation. He made effort to explain why simulation is sometimes and wrongly considered as having a poor value for exercising. It is the result of some persistent misunderstanding between users and developers. The speaker emphasised the importance of including M&S sponsors primarily in the fielding phase: developers should better understand the requirements and users should realise the underlying limits of simulation. The first purpose of simulations is to stimulate. They are never perfect but they always provide benefits. The General related his own experience with constructive simulations: he considered that they should never be used for prediction. Very often military people complain about the fact that computer simulations do not provide realistic results. This may be avoided paying more attention to the establishment of adapted databases and to the preparation of exercises.

In the future, a unique simulation will not be sufficient. A strategy should be established for the development of simulations. All nations should be involved. The General was firmly convinced that M&S will provide useful tools required by the Alliance.

NATO Military Keynote address

Col. J. MOORE, NATO, SACLANT

The speaker mainly concentrated on the support that M&S could provide for main NATO activities: defence planning, training, exercising and military operations. M&S should also support NATO Concept Development and Experimentation (CDE). So, he briefly explained what is CDE and described the CDE process. He presented an overview of the available tools in different areas of usage assessing their value using the well-known traffic light image (green, yellow, and red). Secondly, he explained how M&S could be used in the full CDE cycle.

Considering NATO operations, M&S are vital components - furthermore, they should be robust and their development should be based on validated methods and certified data. Finally, their results should be credible to the operational community.

Finally, M&S should form a key part of NATO research and should also support the overall CDE.

NATO Technology Keynote address

Capt. (ret.) Archangelo SIMI, Head, Naval Armament Section, NATO

"Future M&S challenges: A NATO perspective" was the title of the presentation. The speaker first presented the NATO Armament organisation. He emphasised the role of M&S in the overall armament process from advanced research to armament fielding. He addressed the counter-terrorism topic and suggested that M&S could offer strong support. He described the overall RTO project to deal with this priority research area.

To illustrate the growing interest of M&S in NATO he introduced the well-known HLA federation project called NIREUS. Thirteen nations are co-operating in this project, not only NATO members but also PfP nations. A videotape was presented which illustrated the interest of this typical project to the armament community.

Industry Keynote address

LTG (ret.) B. A. C. DROSTE, Chairman, Netherlands Industrial Simulation Platform SIMNED, Delft, NE

The first part of the General's presentation was generic. He considered that research and development are impossible without M&S. The General reported his own experience as an air force pilot on flight simulators relating their benefits and the improvements that they could offer in the future. He briefly reported on the national activity: the "Netherlands Simulation platform" called SIMNED, which was created in 1994. He provided some examples of promising activities showing the considerable potential of M&S in different domains: first, PC-based training simulations; second, the threat evaluation based on constructive simulations; third, the training of inexperienced car drivers to face very difficult traffic situations.

The second part of his presentation was a short introduction to some typical Dutch projects, identifying main actors and some important industry organisations. For example, the TACTIS simulator suite, which is a research project of TNO. The speaker also introduces the National Aerospace Laboratory (NLR), the Siemens company, the Delft University of Technology (DUT). His primary message was to illustrate how simulation could be based on COTS products: M&S should be simple, low cost and feasible.

Session 1: M&S Organisations, Perspectives and Policy

Chairman: Dir E. SCHWAN, Germany

- **1. CAX Training and Simulation for the Slovak Armed Forces**

by Col. P. NECAS, Prof. F. OLEJNIK and LTC F. BETKA, Slovak Air Force Academy, Kosice, SLOVAK REPUBLIC

First, the speaker briefly presented his vision on the future Slovak national use of M&S, recalling that the Slovakian Republic has the hope to be integrated soon within the North-Atlantic alliance. Then, he mainly focused on the national CAX activity, emphasising that it should be considered as a cost saving when compared to field training exercises in this period of shrinking budgets. The CAX Slovak philosophy is very similar to and consistent with the NATO one. The presentation was interesting, but the speaker provided little information on his national organisation, which should have been the main subject of his talk. Conference attendees could refer to the text of the presentation for more specific information.

- **2. The Modelling and Simulation Paradigm - A Swedish Perspective**

by Dr S. PALMGREN and Dr G. ROXSTRÖM, Swedish Defence Research Agency, Linköping and Stockholm, SWEDEN

The speaker provided a good presentation, which was organised in two different parts. First, he provided detailed information about the recent Swedish organisation and M&S strategy. Second, he introduced the very original view on what is called "Cognitive Classification of Contents of Organizational Memories", inspired by the Dutch Wijnhoven work (1999). He proposed the establishment of a "knowledge network": "A forum open to the defense community to inform and discuss news and problems in the field of M&S". He suggested that it is the right way to really share experiences and progress in this knowledge community. He proposes to use the acronym "M&S&A" instead of M&S emphasizing the importance of Analysis. The paper corresponding to the presentation rapidly introduces the subject and provides some detail, but not sufficient to comprehensively cover the subject.

3. Development of the Slovenian Simulation Centre,

by Dr T. SAVSEK, MoD, Military Education Center, Ljubljana, SLOVENIA

The Slovenian M&S activity really started with the project SSB (Simulation System of Battlefield, initiated in 1994 and achieved in 1998) to support future national Command Post Exercise (CPX) activity. The M&S basis for this project was, first, the well-known HORUS German tool (brigade level and above) and, secondly, the famous US JANUS model (at battalion level) used to support CAX for Peace Support Operations. The speaker briefly introduced the Slovenian philosophy on CAX, which is consistent with the general vision of NATO. Slovenia has recently established a centre for simulation named DORSA (Department for Operations Research and Simulation). Slovenia is strongly supporting the establishment of a PfP Simulation Centre. The Slovenian Republic will participate in SSESIM 2002 in Greece, an exercise based on JTLS, which should provide additional experience in the CAX activity.

It was an informative presentation. More details can be found in the corresponding paper. Both provide a very good example of how PfP nations can successfully initiate a training capability based on simulation.

Session 2- Support to Operations: Training at all Levels

Chairman: Col. J. J. DE DIE, The Netherlands

- **4. L'outil d'entraînement d'états-majors au niveau opératif /Operative Level HQ Training Tool**

by Cdt. C. CAZOULAT and ICT H. BUENAVIDA**, *EMA/TSIC7, Paris Armées, **DGA/DSP/CAD, Arcueil, France*

The speaker introduced the French Joint Staff M&S vision and the main objectives of the ALLIANCE project. This ambitious project has the primary objective to help the French Joint Staff to better specify its requirement for future CAX capability at the CJTF level and the second objective is for decision support. He recalled what are the main steps of the ALLIANCE development, which was reviewed in accordance with the previously established priorities of the Joint Staff. The French CAX concept was previously introduced during the 1999 and 2000 NATO NMSG conferences. The concept then was briefly described and the presentation mainly focused on the ALLIANCE project itself.

Navy, Land and Air simulations supporting the project were described. Other useful tools were also introduced. Tools such as information servers or after action review devices are less often promoted, but they are equally important in every CAX activity. This prototype project is a first but important step toward a true national operational capability. It will be used as a basis in the next French exercise OPERA in 2003.

- **5. Improving Combat Dynamic Intuition - The Minimalist Approach.**

by Mr B. T. BAKKEN, Mr M. GILLJAM and Dr B-E. BAKKEN, NDRE/FFI, Kjeller, NORWAY

Decision support and training of high commanders are generally envisaged as requiring a high degree of support by sophisticated, costly and time-consuming tools based on the best technology. Many people worry about the cost, and question the intrinsic capability to afford them. The speaker focused on a different approach called the "Combat Dynamic Intuition" (CDI). According to the authors, "CDI is the ability to intuitively comprehend what are the likely combined outcomes of the inherent dynamics governing the situation, and the decisions made to act upon the situation". The presenter first analysed how the decision

cycle is generally understood. The main idea is to examine how decision making skills could be built in a simplified/minimalist environment, before these skills are transferred to more complex, “sharp” situations. This constitutes a very specific and innovative approach. The corresponding paper is highly recommended for further reading.

- **6. From Legacy Simulation to Interoperable Distributed Simulation: the Alenia Aeronautics Experience**

by Mr M. FABBRI and Dr S. CERUTTI, Alenia Aerospazio, Torino, Italy

The speaker briefly introduced main activities of his company in the M&S domain. He recognised that it would be better to move toward a more integrated Synthetic Environment vision, but it is a very ambitious and probably unrealistic approach for every organisation. Alenia recognised that the entire HLA technology has been developed to specifically address this issue. Current Alenia activities aim to demonstrate technical feasibility of using the HLA in the Flight Simulation department. An experiment has been initiated on a distributed connection of real time simulators between Turin and Genoa.

The paper also describes other activities carried out at Alenia Aeronautica, as well as projected development towards a systematic use of this novel architecture. This presentation and the corresponding paper provide an interesting overview on the M&S philosophy of a large company.

Session 3: Support to operations: Communication systems and M&S

Chairperson: Ms L. McGLYNN, US

- **7 Modelling Command and Control Teams**

by Dr J. Van den BROEK, Dr P. ESSENS and Dr W. POST, TNO Human Factors, Soesterberg, The Netherlands

Modelling and simulating C2-team behaviour is the ambitious objective of a department of the Dutch TNO. The selected approach was clearly exposed by the presenter and it offers some obvious merit. The developed tool is named IPME (standing for "Integrated Performance Modelling Environment"). The main conclusion derived from this work is that team modelling is feasible, following the assessment of the previously completed work. This is an “easy-to-read” paper and one of the most original addressed in this conference. The paper is highly recommended to those who are interested in C2 systems design and development.

- **8. SINCE: a New Way of Doing Business**

by Dr D. KLOSE, Mr C. SHETH and Mr A. RODRIGUEZ, US Army CECOM, Fort Monmouth, NJ, USA

The speaker reported ongoing effort based on the HLA. He firstly commented on challenges facing the US Army, which must be consistent with and strongly evolve to take into account allies different means and technological levels. With respect to the preceding Dutch project, the CECOM project shares an interest for assessing new C2 System interoperability concepts.

Concerning the “Simulation & C2 Information Systems Connectivity Experiments” (SINCE) effort, it is both an Internal US experiment and a Joint cooperative effort with Germany. The presentation was very intense and difficult to follow for non-specialists. Specialists of the topic are recommended to read the paper to obtain deeper understanding.

- **9. The Tendencies of Modelling and Simulation Development in the Bulgarian Army**

by Dr J. KARAKANEVA, Defence Advanced Research Institute, Sofia, Bulgaria

The speaker first introduced her national organisation. She then presented the Bulgarian ambition to join NATO and explained how main M&S activities are directed to support this objective. M&S play an obvious and important role in this process. The audience was quite interested to observe how this nation has realised the potential of M&S for future development. The presenter ended her presentation with an overview of the projects ongoing in the Bulgarian Army.

That was a good presentation showing a high level of maturity of Bulgaria in this area, which provided encouragement to NATO members to continue and reinforce their co-operation with PfP nations. It also demonstrated the interest of M&S as a vehicle of common culture and understanding.

Session 4: Future trends: Virtual Forces and Artificial Intelligence
Chairman: Dr G. J. JENSE, The Netherlands

- **10. Developing Vehicle Survivability on a Virtual Battlefield**

by Dr J. RAPANOTTI, Ms A. DeMONTIGNY*, Mr M. PALMARINI** and Dr A. CANTIN*, * Defence Research Establishment Valcartier, Val-Belair, ** Onix Integration Inc., Ste-Foy, Quebec, Canada*
The speaker introduced a very specific but nevertheless interesting subject. He demonstrated that current well-known tools could be used with profit to solve typical military issues. The main interest of this presentation and the corresponding paper was to introduce how the changing world has transformed the concept of armoured vehicle, which demonstrated the high level of military expertise of the authors. Considering M&S methodology and its application, the paper lacks specific details on the way of validating the selected approach.

- **11. Modelling of Combat Actions via Fuzzy Expert System**

by Mr Z. GACOVSKI and Col. S. DESKOVSKI**, *Ministry of Defence, **Military Academy, Skopje, Former Yugoslavian Republic of Macedonia*
That was a very theoretical presentation and a modern update of a former and well-known modelling approach. The presenter showed a great merit in extensively presenting the approach in a very short time slot! Only those with a very specific interest in the subject are referred to the paper. A large amount of work still remains to be undertaken in order to implement and validate this modelling approach.

- **12. A Tactical Planning Approach by Using Artificial Intelligence Procedures**

by Maj. J. M. CASTILLO and Prof. F. de ARRIAGA**, *Escuela de Informática del Ejército, **E.T.S.I. de Telecomunicación, Madrid, Spain*
The speakers clearly introduced their current work. At first sight, this could be regarded as another very scientific paper, but in fact it was based on a very pragmatic approach dealing with a real problem. The use of intelligent agents was the basis for this application. The proposed solution was implemented as a prototype that should be considered of the first operational version of a tool. This was a very good presentation, which succeeded in clearly presenting a very difficult topic. This presentation was one of the best of the conference. The paper is also excellent and easy to read.

Session 5: Future trends: Gaming and Agent Technologies
Chairman: Ob. H. G. KONERT, Germany

- **13. Incorporating Aspects of Human Decision Making in Task-Network Simulation Tools**

by Dr W. WARWICK and Ms. S. ARCHER, Micro Analysis and Design, Boulder, Colorado, USA
This was a very clear and interesting opening presentation, which was related to the modelling of human behaviour and performances. The speaker reported on three different projects focusing on the 'task-network" approach. This is an excellent paper which is related to papers and presentations 15 and 12 (paper 12 would have been better placed in this session). This presentation showed interesting progress on the means to represent human behaviour. The corresponding paper is highly recommended.

- **14. A Low Cost Dismounted Infantry Trainer Derived from Gaming Technology**

by Mr D. WRIGHT, Royal Military College of Science, ESD/AMOR, Swindon, Wilts., UK
The paper and the presentation report on work completed to assess the usability of a particular game for training dismounted infantry. The results presented are promising as they demonstrate that the gaming industry could provide very good tools to the military community. Obviously this is a very particular application and caution needs to be exercised before generalising the conclusion. However, it highlights that co-operation between the military and the gaming worlds may be beneficial. This is an excellent paper, which provided for the first time an optimistic view of the application of “games” for military training.

- **15. Une plate-forme intégrée autour du noyau DirectIA pour la simulation militaire: résultats d'une étude reproduisant un exercice tactique/ An Integrated Platform for Military Simulation Based on the DirectIA Kernel: Tactical Exercise Reconstruction Results**

by Dr E. CHIVA and Dr J.Y. DONNART, MASA Group, Paris, France

The speaker introduced an original piece of work, completed by his society, which has the primary activity of producing tools and simulation engines for the gaming industry, and more recently for military clients. The purpose of the presentation was to introduce the "DirectIA engine", which is an improved methodology avoiding the drawbacks of decision trees in terms of required computing power and memory and which, also, provides a better capability to evolve.

The paper is recommended since the approach is one derived from operational experience and application specifically for the French Army. It is also recommended that the proposed methodology and tools be carefully monitored in the future, as a potentially new and promising way to support human behaviour modelling in the military area. This presentation concluded the best session of the conference.

Session 6: Future trends: Long Term Previsions and Perspectives

Chairman: Graham BURROWS, NATO MSCO

- **16. SIMTECH 2007… and beyond**

by Ms. L. McGLYNN and Dr S. STARR**, *ODUSA(OR) M&S and Light Forces Studies, Pentagon, Washington, DC, **MITRE Corporation, McLean, Va., USA*

This paper summarised the main findings of a former series of workshops held in the US with SIMTECH 2007 being the last workshop in the series. This was a presentation highly related to the conference theme. The presenter had the difficult task to provide the audience with a flavour of the rich set of findings from this important work. Readers are recommended to the paper and also to the CD-ROM published after SIMTECH 2007, which provides a full extension of the major results of the workshop. The feedback on the previous SIMTECH 1997 (unfortunately not presented at Breda) is regarded as the most important aspect part of this work.

- **17. The Method of Construction and Learning of Local Combat Generator**

by Col. A. NAJGEBAUER, Col. T. NOWICKI and Lt J. RULKA, Military University of Technology, Faculty of Cybernetics, Warsaw, Poland

The speaker first introduced the idea of a local (or closed) combat generator. This project was set up to provide a fast and preliminary answer to CAX requirements for the Polish Army. The presenter quickly explained the underlying mathematical model, which is mainly based on stochastic modelling: a classical method, but re-visited, correctly applied and implemented using modern technology. The ensuing discussion raised difficult issue of the VV&A of this kind of model. This was an excellent presentation and a good paper.

- **18. Multi-agent Work Practice Simulation: Progress and Challenges**

by Dr W. J. CLANCEY and Dr M. SIERHUIS, NASA Ames Research Centre, Moffett Field, Ca., USA

This was a clear talk presentation, which introduced ongoing work within NASA that was directed to better understand how people work together. It provided a good window of the outside world from the military community. The speaker introduced BRAHMS, which is a simulation tool for representing the interactive behaviours of people and objects in a simulated world. Despite the great talent of the speaker the presentation was too short to diffuse the information contained in a very detailed paper. Hence the reader is recommended to the paper for a detailed exposition. The author considers that several decades of research will be required before a full and satisfactory solution can be found to the modelling of interactive human behaviour.

Session 7: M&S Best practices: VV&A
Chairman: LTC C. HADINGER, USA

- **19. Ten Commandments for Modelling and Simulation Fitness for Purpose**

by Mr R. MAGUIRE, QinetiQ, Aircraft Test and Evaluation, Salisbury, Wilts., UK
The speaker reported on work completed during a series of workshop on M&S Credibility and "Fitness for Purpose". This was an excellent introduction to this session, which deals with a very general topic. The presentation was very clear, but the reader is recommended to the paper, which provides much additional detail on the UK approach to this subject, which is very different from more traditional approaches. It is recommended that the Ten Commandments, should be recorded in every "good practice" book on VV&A.

- **20. A Methodology for Verification and Validation of Models and Simulations: Acquirers' View Point**

by Lt. Cdr. O. MOLYER, Scientific Decision Support Center, Turkish General Staff Hqs, Ankara, Turkey
This is an interesting paper and a good presentation. VV&A presentations are usually provided by designers and implementers: so it was gratifying on this occasion to hear from their clients. The paper refers to "Verification and Validation", however it mainly deals with "Validation and Accreditation". The fact that the sponsor/client of a simulation are involved in the complete cycle of development from the requirement analysis to the final testing, is mentioned as evidence in accordance with the general feeling of advanced practitioners.

- **21. Challenges for Distributed Exercise Management: the SmartFED Approach**

by Ir. M. KEUNING, Drs E. van de SLUIS and Dr A. ten DAM, NLR, Amsterdam, The Netherlands
This was a very clear presentation on a tool suite, which has been presented in other conferences and workshops. The SmartFED tool-suite is mainly used for developing and managing federated exercises. It claims to provide some capability for supporting VV&A, but the paper and the presentation show only a capability to help in Verification, which is a technical activity. The paper provides a high level view of SmartFED, which apparently is a very useful tool for developing and running real-time federations. The accompanying paper regretfully does not contain detailed technical information.

Session 8: M&S Best Practices: Standards
Chairman: Cdr. G. AMEYUGO-CATALAN, Spain

- **22. Areas of Simulation Standards**

by Dr E. NEUGEBAUER and Mr D. STEINKAMP, CCI GmbH, Meppen, Germany
A great step forward has been realised with the invention of the HLA interoperability standard. But, unfortunately, HLA is not self-sufficient: without data standards, its use will be difficult and in some situations not possible to use. For this reason, the reader is referred to the paper since it is dealing with an issue of some concern. A report referenced in the paper (far more detailed than the corresponding paper) was provided to NATO by Germany and has been distributed to NMSG members to initiate future NATO effort in this domain.

- **23. Environnement modulaire pour l'interopérabilité des systèmes – GTI-6 /Generic Toolbox for Interoperable Systems – GTI-6**

by Mr V. SAILLOUR and Mr D. CLAUDE, EADS Launch Vehicle, Les Mureaux, France
This large project was the first coming from a non-military community (the space domain) completed in France using the HLA. A first experiment took place in 2000 between France and Germany, in the context of the EDISON project. It provides a clear proof that hardware-in-the-loop simulation interoperability, in the acquisition system domain, can be a cost saver.

- **24. The Agent Based Simulation Opportunity**

by Dr P. BARRY, The MITRE Corporation, McLean, Virginia, USA

The speaker developed a large overview of the agent technology. He was convinced that this technology is sufficiently mature to be extensively used in the M&S world to-day. However, it is not obvious that there is a significant number of successful applications that demonstrate this fact. Nevertheless, it is important that the military M&S community monitor intelligent agents in a continual quest to better represent human behaviour. The paper is recommended and easy to follow.

Conference Closing Remarks

By Maj. Gen.(rt'd) E. MARGHERITA, TNO Board of Management, Delft, The Netherlands, (presented by Mr Hans PASMAN, Director of TNO Defence Research)

The speaker briefly introduced the TNO organisation before introducing the history and evolution of M&S in his laboratory. Mentioning his past experience, he carefully recalled that simulation would never replace thinking. Nevertheless, he emphasised that excellent progresses have been achieved in the technology domain since the 70s and considered the future to be bright for M&S. But, much work is still required to achieve a true operational capability in M&S. Finally, he listed many tasks, which still require to be solved. The list is impressive and the “Challenge is to co-operate, to team and to unify!”

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Royal Military Academy –
Welcome Address

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Host Nation – Welcome Address

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NATO Keynote

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Good afternoon! I appreciate this opportunity to share my thoughts with you about training modeling and simulation. My remarks will focus on the utility of models and simulations in military training. I am certainly no expert, but I do have some experience in this area. I received your invitation to speak at this conference while serving as the Commander of the Joint War-fighting Center, a part of the America's Joint Forces Command. My time at the Center, along with my time as the Commander of the 4th Infantry Division, the U.S. Army's first "Digital" Division, as well as my days at the National Training Center in California, have given me a perspective on Simulations, modeling and training. My views may not be completely right, but I know they're not 100% wrong either.

I consider myself a Simulation Abuser… not a Simulation User! My perceptions of simulation utility in training have been both, positive and negative. How positive the positive, and how negative the negative is the fault of neither the Simulation Developer nor the Simulation User… Rather a combination of the two. Simulations need human interaction both during development and more importantly, during fielding and use to make them a viable training tool. Far too often, developers create the ideal suite of simulations, then leave it to the user to determine the best means of utilization... this is a recipe for failure.

Developers are not usually in direct and frequent contact with military users. And, military users don't normally provide specific guidance to simulation developers. The end result is usually a great simulation with limited training utility. Frustration grows on both sides because training objectives cannot be met by a simulation considered sub-optimal by the training audience.

How do we solve the problems just mentioned? There are several approaches worthy of consideration:

First, developers must understand requirements and users must understand capabilities. This shared understanding of requirements, capabilities and limitations is, I believe, the first step in successful simulation development. By the way, when I refer to users, I mean "USERS," with a Capital "U;" the commanders and leaders who will use the simulations in training. These are not to be confused with simulation developers who happen to wear uniforms.

Second. We all understand that with an infinite amount of time and an infinite amount of money, we can create a perfect simulation. Unfortunately we have neither the time nor the money to achieve perfection.

What must be developed is a common understanding of need. Simulations should provide training that is Good Enough; they don't have to be perfect, they merely have to stimulate the training audience toward achievement of their training objectives.

Finally, we must plan for the inevitable… that once in the hands of the user, the user will want changes made. I believe a significant percentage of development energy and money should take place during the post-fielding stage, a sustainment and improvement phase of simulation development. We need to treat simulations as the dynamic software programs they are rather than a finished, static product… my experience suggests that we don't normally do this well.

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A simulation used in training should be seen for what it is: A cost effective, virtual training opportunity to practice processes and rehearses simulated combat engagements.

For example, the tactical instrumentation used at the Combat Maneuver Training Center, at Hohenfels, Germany provides a realistic experience of what happens on the battlefield. The Multiple Integrated Laser Engagement System, better known as “MILES” provides Force-on-Force field training for maneuver units. It is far from perfect, but it does resolve the issue of “Who shot whom,” and places the focus on tactics and execution. The lethality and suppressive effects of weapon systems, like the 155 MM Howitzer, can be demonstrated in simulation as well, again not perfectly, but good enough to give our formations a true “First Battle” experience before actual combat.

But remember, they only have to be good enough. They are training tools used to refine the mental agility and tactical acuity of commanders, soldiers and staffs on the virtual battlefield.

As another example, Constructive Simulations provide a relatively high resolution of activity for participating forces. These constructive simulations are normally used for higher-level commanders and staffs to rehearse and execute the full range of staff battle skills… intelligence gathering, resource monitoring, and mission analysis… all of which lead to the practice of real time decision-making.

Although constructive simulation doesn’t provide real combat results, and should never be used as a predictor of combat outcome, it does serve to capture the imagination of the participants placing them in a dynamic competitive environment and gives them enough of a realistic feel to keep their heads in the game… again a realistic first battle experience.

Both, Tactical instrumentation, like MILES, and constructive simulation, like the U.S. Army’s Corps Battle Simulation (CBS), require commitment from the training audience to use this training tool to their advantage in order to maximize its affects. Tank crews that can’t bore-sight their MILES gear will not be successful on the battlefield and will loose the opportunity to gain valuable training.

When using Constructive Simulations, commanders must commit time and resources to train their support cadres in the simulation center. I can’t begin to tell you the number of commanders that I have seen who complained about the simulation being unrealistic, producing unrepresentative results. In virtually every case this is due to the fact that the complainant has placed marginally trained or inexperienced junior officers in positions within the simulation centers to play the role of a higher-level commander. The results are predictable... the simulation doesn’t care if you are Napoleon or Mickey Mouse, it will provide results based on your inputs. Placing a lieutenant in command of a simulated carrier battle group to help train the fleet staff has predictable and disappointing results. If you want quality training, you must pay a price in preparation, people, and time.

What does this have to do with NATO Modeling and Simulation? Based on my experience, I believe there are four take-aways for you. Four points I would ask you to consider.

<u>First</u>: Realize, no single simulation will meet all training needs. Leaders need to use their judgment and experience to establish a simulation strategy that will define purpose and frequency of use. This should be done before you enter into simulation production, or before modification of existing simulations for future use.

<u>Second</u>: All parties need to commit to the development of the simulation... users and developers alike. All players need to be involved… bystanders need not apply.

<u>Third</u>: In the world of simulation, we can spend plenty of time and money seeking perfection. This isn’t a necessity in meeting training objectives. Invest in “Good Enough” and the ability to alter simulation tools over the lifespan of the simulation as needs and requirements change.

Finally: Regardless of the Simulation’s strategy and training value, Users have to accept that detailed preparation will play a major role in providing the desired output. Today’s preparation equals Tomorrow’s Success!

Don't let me leave you with the impression that I know everything or anything about simulations. These are only my observations based on my experience. I've seen simulations that have worked well, and those that have worked poorly.

These points are meant to encourage discussion and perhaps provide some useful thoughts on what improvements can be made in modeling and simulation for the Trainer and the target audience. Regardless, I am absolutely convinced that simulations and their thoughtful use is the only feasible and affordable means to prepare joint and combined forces for the Challenges of the 21st Century Operations.

Thank you again for the opportunity to share my views with you. I hope you have a successful conference.

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NATO Military Keynote:
NATO CDE & Modeling and Simulation

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NATO Technology Keynote:
A NATO Prospective

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Industry Keynote

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CAX Training and Simulation for the Slovak Armed Forces

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Abstract: *Modeling and simulation has long been utilized to improve training, develop doctrine, tactics and materials, and improve combined and joint coordination. The ability to develop a versatile CAX planning and execution procedures for Training and simulation centers equipped with standard tools has always been a challenge.*

Keywords: *Training, Capability, Simulation, Information, Modeling, Concept, CAX Design, Planning and execution, requirements based CAX. MSEL, Constructive simulation, After action review,*

Introduction

Exercise form, definition, and products mature in a progression from general to specific, draft to final, from general concept through detailed plan to execution and feedback with course corrections and decision points along the way. Training and Simulation Centers (TCS) support and participation in exercises consists of activities related to the four segments of an Exercise Life Cycle (ELC): ***design, planning, execution, and post-exercise activities.*** This paper describes the exercise segments and their components in general terms. It also contains a generic milestone schedule of key exercise events. Although the four segments of an exercise cycle generally apply to all exercises, the components of each segment may vary in terminology and scope during individual exercise development, depending on the complexity or purpose of the particular exercise.

Design

The design and pre-planning segment of the ELC nomially begins with a Pre-IPC (Concept Development Conference) meeting hosted by the appointed exercise director. This meeting is normally followed by a Central Planning Team Meeting (CPTM) and ends with a decision concept brief to the exercise director. The approved exercise concept, thenremains intact and is built upon during the ELC. Subsequent plans are developed to implement the concept.

Concept. The ELC starts with an exercise concept. The concept establishes the who, what, when, where, and how of an exercise. It provides the purpose, scope, participants, type of exercise, and dates.

Exercise and Training Objectives. Exercise and training objectives are developed in tandem with the concept. Exercise Objectives are the objectives of the Exercise Director and what he intends to achieve with the exercise. Training Objectives are the goals of the Training Audience and are usually linked to the unit's Mission. Together they form the basis of the After Action Review (AAR) planning and ultimately determine

the desired gain from an exercise. Objectives should be limited in number, measurable by data collection, and stated clearly.

Exercise Specification (EXSPEC). This is a key document that captures and provides initial planning information and guidance and is published well ahead of the exercise to permit detailed planning by participants. The EXSPEC contains the exercise purpose, objectives, exercise dates and duration, location(s), scenario, participation, phases, and planning milestones. The EXSPEC is the foundation for the follow-on and much more detailed Exercise Directive (EXDIR).

Scenario and Road to War.

- The scenario provides the background for an exercise and the framework within which to operate. The exercise scenario postulates events, weather, and situations that participants encounter during an exercise and must respond to. The scenario must be plausible and sufficiently detailed to provide realism and stimulate participants.

- The road to war, a subset of the Scenario, is a chronology and description of specific and significant events that lead up to the day the exercise starts (STARTEX). This normally requires at least a 90 day buildup.

Memorandum of Agreement. If used, this important document establishes the roles and missions of the TSC and the sponsoring and supported headquarters for the exercise.

Planning

The planning segment of the ELC normally begins after the first meeting with the appropriate Military designated headquarters conducting the exercise and ends with the final progress review meeting with the designated exercise director. The exercise concept will take on changes as it matures under the guidance of the sponsoring headquarters or the exercise director. Supporting plans and annexes are developed to implement the concept. Final plan will have a “cut-off” date to allow the planners and TSC sufficient time to prepare the model and facility to support the exercise.

Exercise Directive (EXDIR). The EXDIR establishes the necessary policy and guidance to conduct the exercise. It identifies the responsibilities of all participating and supporting organizations for planning, conducting, controlling, and assessing the exercise. It expands the exercise concept articulated in the guidance from the exercise director to include administrative details, logistic requirements, automated data processing and communications support, public affairs provisions, and the analysis scheme. Most exercise directives contain a series of annexes that address functional areas.

Exercise Control Plan (ECP). This plan is a key document; it is an annex to the EXDIR. It is restricted to control personnel ("trusted agents") and contains guidance to the Exercise Control Group (ECG). It describes the exercise control concept, organization, functions, and responsibilities; outlines the control organization; provides control instructions; provides Director Staff (DISTAFF) procedures; provides simulation control procedures; and contains a key events list and a chronology of expected events. These events are based exercise and training objectives and may include "free-play" computer simulated actions programmed by a Master Scenario Events List (MSEL).

Master Scenario Events List (MSEL) and Injects. The MSEL is a list of sequenced events that are planned to occur during an exercise through controller injection of implementers as well as through simulation. Implementers (e.g., memoranda, messages, telephone conversation scripts) are injected into the exercise to require participants to respond to a situation in support of exercise and training objectives. There is a direct correlation between MSEL events and the After-Action Review Data Collection Plan (AARDCP).

Opposing Forces (OPFOR) Campaign Plan. This stand-alone plan is designed to facilitate accomplishment of the training objectives. It is linked to the master scenario that provides the background for and sets the conditions for how the OPFOR will operate. The plan is developed in concert with the scenario and road to war, to ensure that it is plausible, realistic and sufficiently detailed to provide the dynamic stimulation to participants.

Simulation Control Plan. This plan describes the simulation center concept, organization, functions, and responsibilities. It is an appendix to the ECP.

Technical Control Plan. This plan describes the model technical operations and simulation site concept, organization, functions, and responsibilities. It is an appendix to the Simulation Control Plan.

Communications Plan. This plan describes the communication concept, organization, functions, and responsibilities. It is an appendix to the Simulation Control Plan.

Exercise Databases and Test Plan. Prior to active play, synchronized databases are developed to reflect exercise situations and scenario events. Some databases consist of unit order of battle compositions and weapons characteristics (for simulation models); others list MSEL events. For exercises addressing mobilization and conflict resolution, examples are Red (enemy) and Blue (friendly) orders of battle, logistics and time phased force deployment files, and communications connectivity. The databases must undergo extensive technical and operational auditing and testing to ensure their consistency, coherency, credibility, traceability, and usability. A rigorous and thorough test plan is essential to validate and verify the databases.

Training Plans. Plans are developed to train exercise support personnel, including the ECG, response cells, observers, and other augmentees. This training is designed to inform the entire exercise support team on the scenario, road to war, the ECP, and the AAR process. It addresses all the training events leading up to the exercise including the MiniEX.

AAR Data Collection Plan (AARDCP). This plan describes in detail what is to be examined during an exercise, the analysis methodology, and the plan to collect supporting data. It is developed in concert with the other plans to ensure that sufficient and relevant data is generated by the exercise and its supporting scenario. The AARDCP directly supports the AAR process and includes analysis areas that are directly drawn from the exercise and training objectives. Analysis areas can also be based on past exercise deficiencies, experience from actual operations, or a desire to quantify operational or support requirements. The data collection methodology provides the details for what data is to be collected, who collects it, and when and where it's to be collected.

Execution

Exercise Training.

- Due to their complexity, most exercises require participant orientations and training. Orientations and training are usually conducted within three weeks of STARTEX to provide the most current information and reduce the probability of last minute changes in personnel scheduled to participate in the exercise. Three types of training sessions are normally held.

a) Participant Orientations. These sessions will be provided by the exercise director or his representatives to include TSC personnel during inprocessing. It will cover the exercise scenario; administrative details; ground rules for simulation actions (response or simulation cells); control guidelines; data collection activities; and, if required, the means for communicating with higher, lower, and adjacent agencies.

b) Controller, Analyst, and Data Collector Training. These individuals receive detailed instructions on control activities and analysis and data collection and may require more training than participants. They receive guidance on exercise locations, travel, security clearances, control techniques, collecting and processing exercise-related data.

c) <u>Senior Participant or Visitor Briefings</u>. Senior officials receive briefings that are condensed versions of participant, controller, analyst, and data collector training sessions. Even though they may or may not be exercise participants, senior officials are often made "trusted agents" and are given scenario and control plan details to facilitate exercise execution and accomplishing their understanding of exercise objectives.

- Exercise planners also may schedule other types of training, such as staff seminars, workshops, and special training sessions for ad hoc organizations to be formed during an exercise or to become familiar with new equipment. The more complex exercises may require rehearsals to test controller communications, data collection plans, response cell and control group procedures. Rehearsals may be in the form of tabletop exercises, a walk-through, or full-scale rehearsals.

Exercise Control.

a) <u>Exercise Control Group (ECG) or Director Staff (DISTAFF)</u>. The TSC or the sponsoring Military headquarters agency establishes an ECG. The number of members and staff sections depends on the size and complexity of the exercise. Normally, the major functional activities being exercised (e.g., maneuver, logistics, fire support) will be tasked to provide representatives to the control group during the exercise. The representatives may serve as role-players, simulating an organization's routine functions by providing scenario-related responses to player queries, or act as an exercise point of contact for actions or queries being routed to the exercise director. Control groups regulate (and modulate) the exercise according to the guidance provided by the director or contained in the ECP.

b) <u>MSEL Implementer Injection</u>. Control groups may insert MSEL implementers into the exercise according to the MSEL schedule; they may eliminate, delay, or modify MSEL implementers to maintain the desired exercise pace. A dynamic MSEL event may be directed by the exercise director when a situation or opportunity presents itself to evaluate a training objective, which may not occur with the model alone.

Data Collection Evaluation and Analysis.

a) Chief of Evaluation and a group of Observer Controllers (OC) will be appointed by the exercise director and will function as data collectors and monitor the primary training audience's performance during the entire exercise. The activity begins with a front-end analysis of the exercise design, exercise objectives, unit training objectives and a cross walk of the higher to lower operations orders that will be executed during the CAX by the exercising unit. This analysis serves as the basis for the development of a collection plan. The completeness of the collection plan provides the common ground for the Chief of Evaluation to lead a professional discussion with the members of the training audience during the After Action Review (AAR).

b) In addition to completing data collection forms, OC Evaluators collect daily situation reports, participant memoranda and messages, briefing slides and scripts, journals and logs, and applicable documents. These materials are necessary to support evaluator observations to determine why an event occurred and how to improve the performance of the unit.

Post-exercise Activities

Most organizations have programs to manage any identified deficiencies and corrective actions taken to resolve problems noted during exercises. Activities may include AARs, an exploratory critique immediately after the exercise; a first impressions report within a number of days after the end of the exercise (ENDEX); an analysis report a number of days after ENDEX; and a remedial action recommendation to correct specific deficiencies. Also, as a normal occurrence following an exercise, the exercise participants should have the opportunity to evaluate the adequacy of TSC support, to include life and facility support.

After Action Review (AAR). Immediately following an exercise, participants are engaged in the conduct of an AAR to discuss the exercise while events are still fresh in their minds. The AAR is a facilitated training

event that uses discovery learning techniques to explore exercise events to determine what happened, why it happened, and how to do it better in the future. Specific statistics to support attainment of objectives may be directed by the exercise director.

Assessment Report. This report, prepared by the DISTAFF using AAR outcomes provides the training audience an assessment of the strategies, policies, plans, procedures, or systems evaluated during the exercise. As such, it is based on an analytic effort that clearly describes the problems, their causes, and possible correction measures. This report is the source document for the commander of the exercising unit to develop remedial actions. It also portrays trends from past, similar exercises and can be used to develop concepts, objectives, scenarios, and analysis areas for future exercises.

Recommendations for Subsequent Exercises. From post-exercise activities or operations described above, planners derive concepts and objectives for subsequent exercises. This completes the ELC.

Exercise Checklist and Planning Milestones.

The typical ELC for each exercise generally covers 12 months (11 months for planning, 1 to 2 weeks for the exercise, and 1 month for post-exercise activities). The main events of the ELC are exercise identification and scheduling; analysis and guidance for concept development, initial planning, final detailed planning; training of all participants, final preparation; MiniEX; exercise; AAR; and post-exercise activities.

For any given exercise, the actual planning schedule will probably vary according the national military doctrine, training strategy and appropriate armed forces manuals.

Summary

The Wargaming involves a replication of warfare without an actual combat force that allows opponents to respond interactively to each other's actions. By exercising strenuously and studying the outcomes, commanders can train their forces to much higher levels of effectiveness, using less resources.

Computer Assisted Exercises provide opportunities for commanders to train their units to the highest levels of effectiveness. One of a mix of training activities, including field exercises and indoor training, CAXs provide a flexible, powerful, cost and time-effective tool for units to train very cost effective and without the risk of vehicle accidents and damage to property. They enable commanders and planners to experiment with alternatives and determine the most suitable courses of action in any given situation. TSC with CAX capabilities provide Slovak Armed Forces with the capability to train cadets, commanders, and staff personnel on developing tactics and procedures.

Over the years, wargames have become increasingly sophisticated and do not always involve combat. Wargaming is a subset of Modeling and Simulation (M&S). Using the power of technology, Computer Assisted Exercises (CAX) can accurately simulate a broad array of high fidelity representations, or models, of modern combat and situational events and permit the Slovak commanders to exercise unit, service, joint, and combined military capabilities across the entire spectrum of military missions for training and the development of tactics and strategy, which significantly supports the process of Slovakia integration to NATO.

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The Modelling and Simulation Paradigm – A Swedish Perspective

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Abstract

The prevalence of Modelling and Simulation (M&S) in virtually all areas from research and development to education and training means that M&S has become a paradigm of modern science and technology.

In order to respond to the general development of M&S itself as well as possible and suitable military applications in the Swedish Armed Forces, a national defence initiative was taken at the beginning of the year 2000. The various steps in this initiative will be described as well as the strategy behind the idea of establishing a self-regulated knowledge network in the area of M&S.

1 M&S within the Swedish Armed Forces

1.1 The Supreme Commander's Position Paper on M&S

In spring last year the Supreme Commander of the Swedish Armed Forces adopted a revised strategy for its modelling and simulation (M&S) efforts. Major motivations for the new Position Paper were the dynamics of modelling and simulation and the need for organising a Section for Modelling and Simulation at the Swedish Armed Forces Headquarter. The authors of this paper have been working within that M&S Section roughly a year and would hereby like to present our experience of some of the work done so far as well as our aims for the near future.

The Position Paper from spring 2000 contains several parts. The main objective is that M&S shall be an accessible, powerful and cost-effective tool assisting the Armed Forces' ability to fulfil its tasks /Viewgraph #1/. Furthermore, M&S shall support enhanced civilian and military ability within and between the following areas:

- Analyses and Studies
- Planning, Command and Control
- Simulation Based Acquisition (SBA) and Armament Procurement
- Education and Training
- Research and Technology (R&T)

The contents of the R&T efforts are devoted to activities of the same kind as the first four headings - although from a different basis. Even if the R&T budget is small compared to the whole (2.3 MECU to be compared to estimated 100 MECU), it is a common belief that the directing of the R&T is of great importance for the whole field of M&S – and not only in the long term. Therefore, all project proposals are assessed in relation to a number of criteria, amongst

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all the relevance and usefulness for the end user in the Military Defence. Also, a balanced capital investment from time to time in the five different areas is a major question.

The Position Paper also resulted in an Executive M&S Plan applicable for the near future and to the work of the M&S Section. It is within the responsibility of the M&S-section to propose and accomplish revisions of both the strategy for M&S-area as well as the Executive M&S Plan.

1.2 The Swedish Armed Forces M&S Environment

Before examining the main problem of this paper, we feel it might be worthwhile to spend a few words on describing the environment for the M&S activities. In this context it might be suitable to present the overall tasks for the Swedish AF and its command structure of today.

The overall tasks for the Swedish Armed Forces are the following five: /Viewgraph #2/.

- Defend the nation against armed attack
- Maintain our territorial integrity
- Be able to carry out international peace-support and humanitarian operations
- Be able to support our society during severe strains and stresses in peacetime
- Have the capability to adapt to altered demands and circumstances

In a way, the list reflects - at least piecewise - a gradual development with inherent time scale of centuries! However, during recent years a dramatic change of the Swedish Armed Forces has been initiated under the name of "Revolution in Military Affairs" – RMA /Viewgraph #3/[1]. The basic meaning of this is to adopt the concept of Network Centric Warfare and CJFT. Therefore both the planning and long-term studies focus on new concepts for the Swedish AF. M&S becomes a necessary tool in evaluating and demonstrating various parts of these new concepts.

The overall command structure for the Armed Forces is shown in /Viewgraph #4/. Briefly, the analysis, plans and major decisions regarding M&S are carried out on the central level shown, including also the War-gaming Centre, while the end-user and certain kinds of problem identifications and feed-forwards in general can be found on regional and local levels. What the picture does not show, is the body of producers of R&T&D (e.g. Defence Research Agency (FOI); the Defence Material Administration (FMV); and the Defence Industries of Sweden).

1.3 A Section for M&S at the AF HQ

As a consequence of the AF Position Paper on M&S, a Section for M&S was established at the HQ during late summer last year. Lieutenant-Colonel Johan Jenvald was appointed the Head of the Section and he rapidly formed a small group - a handful - of scientists, analysts and staff personnel. The group can be taken as a classic example of teamwork amongst people with different backgrounds, education and experience.

The ultimate objective of the M&S Section was – and still is – to "investigate, propose and establish new structures to govern and direct the modelling and simulation activities in the Swedish Armed Forces" /Viewgraph #5/. The interpretation of this fundamental goal has been the most difficult part of the work so far. Our present thoughts and beliefs in this respect are in fact the main objectives for this paper.

With the backgrounds of the inherent dynamics of the M&S area, of the M&S environment in the Swedish AF, and of the multitude of the ongoing activities and applicability of M&S, it is easy to see in what way the utmost objective *cannot* be dealt with: there is no centralised decision making process that can exert a complete and efficient influence on all the activities in the field M&S. The similarities and analogies between the governing of the M&S area and the "Net Defence" are, however, striking.

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[1] By the courtesy of Brig. Gen. Swen Persson, Commandant Swedish Defence Wargaming Center, AF HQ, Stockholm, Sweden.

Such thoughts led us to try to establish a “knowledge network” within Sweden in the field of M&S. The idea itself is very appropriate today, but in order to be able to describe and discuss theories and practices regarding a possible knowledge network, we try to join two basic perspectives /Viewgraph #6/. The first one comes from the consideration of a knowledge network as a part of managing organisational memory; the second one evolves from modern theories and formal methods of complex network. An overwhelming flood of literature can be found on each of the two perspectives; in this paper we will deal with the subjects in a brief and concise way in the following two chapters.

1.4 Political Support

Since the Supreme Commander adopted the new strategy for M&S activities in Sweden, two independent Commission Reports have been published /Viewgraph #7/. Although they deal with subjects much broader than M&S, they both recognise and describe the importance of M&S. The first Report was about Research and Development for the Defence and the other dealt with Defence Material Acquisition. The reports were consistent in their statements that more effort should be spent on early phases of R&D and that the procurement processes no longer can be treated as “linear”. The reasons for increased efforts on R&D, Studies, Simulations, Demonstrators and Trials were explicitly described, as was the importance of the defence community to work together on a broad base in the form of Integrated Project Teams (IPT).

2 Managing Organisational Memory

From our short review of the environment of the M&S in Sweden, we now move to a more general perspective, that of Managing Organisational Memory. In the presentation that follows, we make use of an excellent review of the subject by Wijnhoven (1999) at the University of Twente, the Netherlands. Interesting and useful views on the relationship between Information Systems and Organisational Memory has been discussed by Stein and Zwass (1995).

The vocabulary used by Wijnhoven (1999) follows the cognitive classification of the contents of organisational memory /Viewgraph #8/: Paradigm, Knowledge, Information, and Organisational Accessible Human Capital are all related to each other. One important part of the concept of Organisational Memory will be the distinction between what knowledge (and information) is person-dependent and what is not, and the possibility to manage such differences.

Although the precise definition of the concept of Organisational Memories have been debated during the 1990’s, the essence can be found in a sentence like /Viewgraph #9/: “(Organisational Memories is) *the means by which knowledge from the past is brought to bear on present activities, thus resulting in higher or lower levels of organizational effectiveness*.” (Ref. Stein and Zwass (1995).) The advantage of such a definition is that it is descriptive, and that it can be applied to all kind of organisations, from local entrepreneurs to nations or global companies. Independent of minor variations in the meaning of the concept itself, it is clear that “Memory Management” has the task of improving the efficiency and effectiveness of Organisational Memory.

Since the Organisational Memory is closely related to how the core competence of a company develops with time, instruments for developing an Organisational Memory Plan and Management are very much similar to those of classical strategy planning. Wijnhoven (1999) has listed the following activities /Viewgraph # 10/:

- Planning and control
- Financing and budgeting
- Organising
- Coordinating and operational management
- Infrastructure development (esp. organisational memory information system)

There are different approaches to design an Organisational Memory Information System, OMIS. Whichever is chosen, the common feature seems to be that the OMIS has to become an organic part of the organisation. Therefore every OMIS has to evolve with the development of the organisation and its people (Wijnhoven (1999)).

3 Complex Network Analysis

The possibilities - and motivations - of analysing complex networks have changed dramatically the last few years. There are several reasons for this; one is an increased realisation of the need for understanding a system as a whole, as opposed to the reductionist's view of system analysis.

The presentation in this chapter, relies very much relies on a review article by Albert and Barabási (2001). Without being an expert on Network Analysis, it is still easy to regard their review article as a benchmark paper. However they focus on the topology of complex network and not so much on the dynamics of complex network.

3.1 Concepts and Measures of Network Topology

In order to be able to describe and analyse a complex network, certain natural concepts and measures have been used. The most prominent are /Viewgraph #11/:

- Path length. The number of edges along the shortest path connecting two nodes.
- Clustering. Describes and quantifies the formation of cliques.
- Degree distribution, or node degree. The spread in the number of edges a node has.

These concepts constitute the basis for three robust measures of the network topology: average path length; clustering coefficient; and degree distribution. It is fascinating that for all known complex network it has been found that the average path length is so limited that all these networks can be described as "small worlds".

For certain specialized network topology – like the random graph – these measures can be described analytically. Modern information technology however, makes it possible to carry out empirical investigations of real networks of almost any kind.

The World-Wide Web (WWW) is the largest network that has been analysed in these terms. The nodes of the WWW are the documents (web-pages) and the edges are the hyperlinks (URLs) that point from one web page to another. The size of this network was close to 1 billion nodes (at the end of the year 1999). Despite the large number of nodes, the WWW displays the small world property independent of the choice of samples and network level.

Several attempts have been made also to model and measure the structure of growing social networks. One example by Newman and his colleagues at the Santa Fe Institute (SFI), NM, USA, can be found as a Working Paper June 2001 on the homepage of SFI. Although the model chosen is very simple, the similarity between the behaviour of the model and the growth of a traditional social network is astonishing.

3.2 The Vulnarability of Complex Network

The fundamental idea in the formation of a network is to achieve a robust system for whatever the application is. That idea is based on the belief that a network exhibits redundant properties. The vulnerability of a complex network should be examined with respect to tolerance against errors occurring spontaneously within the network as well as deliberate attacks on the network.

Special cases, which have been studied and described by e.g. Albert and Barabási (2001), involve the removal of edges or nodes. It is understandable that the removal of nodes inflicts more damage to the network than the removal of edges, but the interesting result is that one has found a correlation between robustness and network topology and the possibility to quantify such differences.

One can show that scale-free networks are more robust than random networks against random node failures, but more vulnerable when the most connected nodes are attacked. It is also generally true that the degradation of a network subjected to deliberate attacks and random failures depends critically on the details in the connection pattern, given the same overall level of redundancy.

Even more intriguing behaviour occurs when the dynamics of the network is studied. Such dynamic phenomena can be either changes in the topology of the network itself or a change in the “traffic” through the network – or both. The long-term stability of the network as well as the difficult question of graceful degradation of the network performance become monumental problems for analysts and scientists to study in years to come. Modelling and simulation represent an indispensable tool in all such works.

4 Knowledge Network for M&S

4.1 Properties of a Knowledge Network for M&S

From the influences of the cited works on formal methods in analysing complex networks, and on management of Organisational Memory, we try to merge these facts and ideas into something useful and constructive which take advantage of new techniques and systems for communication and information distribution processes.

The general goal of a Knowledge Network /Viewgraph #12/ should be that it is a forum open to the defence community to inform and discuss news and problems in the field of Modelling and Simulation. The scope and the topology of the network should be such that the network is robust in the sense of being able to allow a multitude of ideas and individual interests to flourish.

If these qualities are achieved, indirect effects of the Knowledge Network can arise. One natural consequence could be that the process of decision making on M&S becomes more effective and accurate; another might be to promote the dynamics of paradigms.

The main tool for establishing a Knowledge Network is /Viewgraph #13/ the development of an infrastructure and the scope of an Information System. One part of the infrastructure will be the newly designed “Technical Reference Facility” – TRA – /Viewgraph #14/[2]. Although some of the activities in that facility will be classified, the structure of the network at different levels can still be described as “open” from a technical point of view.

Due to the condition of an organic Organisational Memory Information System (OMIS), it is believed that the growth of an OMIS should be organic from the very beginning. Fragments of an Information System can then be found in the ongoing review of M&S activities in Sweden.

4.2 Important Tasks for a Knowledge Network in the Near Future

The prevalence of Modelling and Simulation in virtually all areas of modern societies is very much dependent on the strong linking between M&S and the development of various parts of Information Technology. The development of application of M&S goes hand-in-hand with the development of M&S itself. A Knowledge Network becomes a tool for R&D; at the same time complex network becomes a subject for R&D.

A number of subjects of different scope suitable to deal with in a Knowledge Network is as follows /Viewgraph #15/:

- Network Centric Warfare and Complex Network Analysis. From metaphor to methods.
- Command and Control in a Network Environment.
- The Infrastructure for a Knowledge Network.

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[2] By the courtesy of LtC Per Nilsson, AF HQ, Stockholm, Sweden.

- Cost-benefit of M&S. Different classes of problems.
- The extension of M&S to M&S&A – more ‘Analysis’.
- The Dynamics of Standards. Leading Party.

5 Summary

The support of a Knowledge Network to govern and direct the multitude of M&S activities in the Swedish AF is under consideration. The authors have given a status report of some of the works, thoughts and ideas in this matter, as well as important issues for such a network in the near future.

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Development of the Slovenian Simulation Center

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ABSTRACT

Currently Military Education Center's greatest concern is how best to improve the level of education and training in military education programs and the command and staff abilities of the Slovenian Armed Forces. There is no doubt that this can be achieved through the establishment of a simulation center, where, through battlefield simulations, a realistic training environment in the areas of tactics, operations and staff work can be created and made available to military school and command participants. In this way particular commands can test their battle plans and arrays and play out particular military scenarios on a battlefield simulator. Computer assisted staff exercises are the most up-to-date form of training. Today many armed forces use this form of training at higher levels of command training in the coordination of joint alliance command work. The development of a simulation center is clearly an important step in the direction of bringing military training and practice in the Slovenian Armed Forces up to modern standards. Locating the simulation center within the Military Education Center (MEC) infrastructure is not an accident of chance. Many simulation centers are located within the military educational infrastructure of other countries, because they stimulate both pedagogical and research work.

INTRODUCTION

Activities in the area of military operations research and combat simulations in the Slovenian Armed Forces started in 1994 with the initiation of a development research project entitled Simulation System of Battlefield (SSB) within the MEC, which was tasked with the following fundamental objectives (Savšek, 1994):

- to do research in the area of internationally-known combat simulations,
- to develop new methods and models that can be applied to combat simulations and
- to establish contacts with institutions involved in the development of combat simulations.

Since then, we have established contacts with some institutions active in the development and use of combat models. Through the PfP and bilateral cooperation we have developed exemplary cooperation with Germany and United States of America.

CAXes IN SLOVENIAN ARMED FORCES

The first computer assisted exercise (CAX) in Slovenia was conducted in 1996 using the HORUS combat model. The preparation and implementation of the exercise involved considerable assistance of German Federal Armed Forces officers from the Center for Operations Research from Ottobrunn, mainly in the areas of methodology, operator training and design of operational plans in compliance with NATO standards. In the technical field, assistance was provided by simulation experts from the IABG company, which developed the HORUS system. Slovenian experts were responsible for all of the necessary equipment: UNIX workstations, local computer network and communications. At the same time all of the terrain, armament, attrition, formation and combat plan data required for the conduct of the exercise were prepared by experts on geographic information systems, operations, tactics and armaments. The preparations for the entire exercise took three months. We also made use of Internet communication options so that physical removal from each other did not impede progress. This cooperation continued in 1997 and 1998. During this period, several joint computer assisted exercises were organized. With every exercise a further step forward was made. More precise data definition, increased exercise complexity and improved self-sustainability in terms of techniques, organization and methodology were elaborated. As a result, the first fully autonomous exercise involving design, data preparation and execution was carried out as early as 1999. One of the essential characteristics of the Horus system is that all data can be generated independently. Figure 1 present an example of the brigade level CAX design.

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

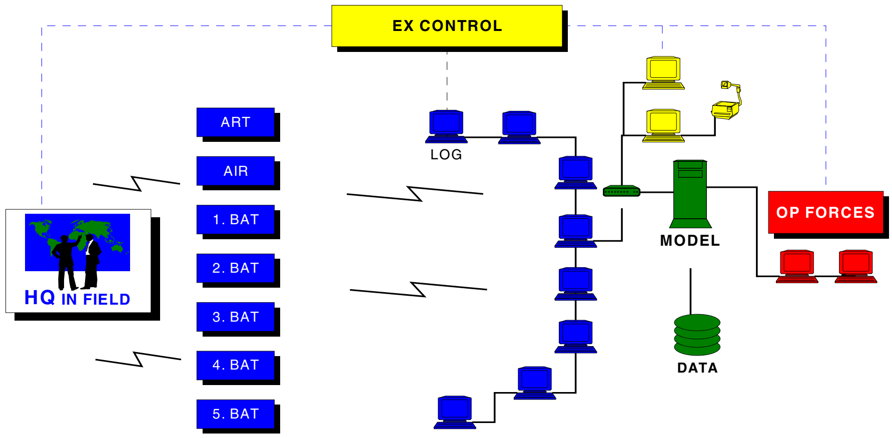

Figure 1: Computer Assited Execise Design

In 1998 the SSB project was completed. Some important conclusions were drawn at the end of the project:

- despite a comparatively moderate initial investment we have become familiar with the technology and methodology of conducting computer assisted exercises,
- as a result of our own exercises we have identified several advantages to CAX,
- we have identified the need for a more systematic organization of combat simulations and operations research.

SLOVENIAN SIMULATION CENTER

The Slovenian government has also a good cooperation with the Government of the United States of America. The Warsaw Initiative has made possible many opportunities, including the purchase of the JANUS simulation system, which is primarily designed to provide computer supported staff exercises at the battalion level for command and staff officer training. The US Government offer includes not only the system itself (i.e. software) but also the appropriate equipment, training of system maintenance and operator staff and consultation in relation to the development of a simulation center, wich was provided by the US Government contractor LOGICON. As a result, more concentrated effort has been put into the development of a simulation center in 1999. In order to accomplish this, the following needs to be done:

- systematic organization of a simulation center under the auspices of MEC - thus far, the entire area of military simulations has been dealt with on a project basis,
- construction of a simulation center facilities,
- designation and promotion of a simulation center.

The reason for our decision to locate the simulation center within the MEC infrastructure is that we already have the HORUS system, from which we have gained valuable experience and insight into military models, battlefield simulations and computer supported exercises. HORUS is a battlefield simulator designed to monitor computer supported staff exercises at brigade-level and higher. Because this system is so open and so easily adaptable, it also functions as a strong analytical tool for carrying out operational research, planning and analysis. With these two simulation systems we are able to cover both the tactical (JANUS) and operational (HORUS) training level areas for Slovenian Armed Forces (Savšek, 1999).

SIMULATION CENTER ORGANIZATION

In 1999 Department for Operations Research and Simulation (DORSA) was established as a constituent body of the MEC. It consists of two sections:

1. Military operations research section - simulation lab and
2. Combat simulation section - simulation center

The basic organisational structure of MEC is shown at the Figure 2.

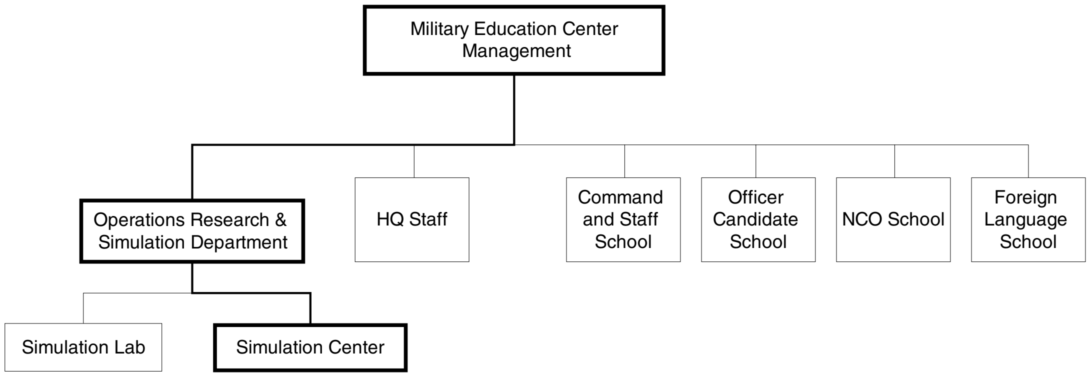

Figure 2: Location of the simulation center within the MEC

Military operations research section - simulation lab

Military operations research section is responsible for professional training and the coordination and execution of military operations research. Operations research is intended for defense and military decision makers, executors and commanders who need scientific answers to issues related to armament acquisition (procurement and development), threat level assessment and identification, damage and casualty assessment, assessment of chances for victory in combat, optimization of force use, optimization of military systems relevant to enemy forces and combat systems, wargaming and scenario analysis. In addition, operations research provides support in the development of tactical and operational doctrine, the demonstration of time factors in movement and the organization and movement of combined formations, integration of all fire support elements, the planning of support and supply to engaged forces, collection and use of intelligence data, use of terrain features and the bringing of support units into line in particular activities.This section will also conduct educational and training programs in the field of operations research as part of Command and Staff School programs and other forms of education and training where such topics are covered.

Combat simulation section - simulation center

The fundamental task of the *Combat simulation section* is to design, develop and provide technical support and perform computer assisted staff exercises using combat simulations in accordance with the annual educational and training plans of the Military Education Center and the Slovenian Armed Forces and according to user requirements. Computer assisted exercises are the most modern and effective method of staff training at senior levels and can be also used in command and staff schools as a supplementary teaching aid. The purpose of computer assisted exercises is to verify decisions and combat plans, prepare plans prior to actual task completion, conduct the wargaming of various war situations for operation preparation, prepare training and plans at a low level of cost and resource use, conduct and evaluate internal staff training and coordinate procedures, develop thinking in modern complex battles, evaluate material and verbal communication processes among commanders and staff members, measure situation response and reaction and staff ability to develop or prepare alternative solutions, review critical decisions at any point in the operation and establish links between functional execution and battle simulation.

With the gradual introduction and standardization of training these activities will be incorporated into regular training programs for combat units and commands of the Slovenian Armed Forces. Simulation center will provide assistance in the preparation and execution of computer supported exercises both from the technical and organizational point of view. Unit and command training will be conducted in the form of exercises with mediators located on simulation center premises and commands at their respective command posts (Command Post Exercise - CPX), or in the form of exercises with the center integrated into international computer supported exercises. Initially, the center will be capable of conducting up to 12 computer supported exercises per year. The center will be also responsible for cooperation in international distributed interactive simulations that are becoming a standard form of command training in NATO and PfP peacekeeping and other activities.

SIMULATION CENTER FACILITIES

DORSA is located at the MEC facility in Ljubljana near the main building of the General Staff. Corridor B is used for simulation center operations (offices for friendly unit mediators, enemy forces, scenario developers, data and operational plans), auditorium for exercise monitoring, analysis and after action review - AAR. The basement rooms were rearranged into command posts. Attached is the schematic plan of room arrangement. Figure 3 shows the organization of simulation center offices in the educational facility.

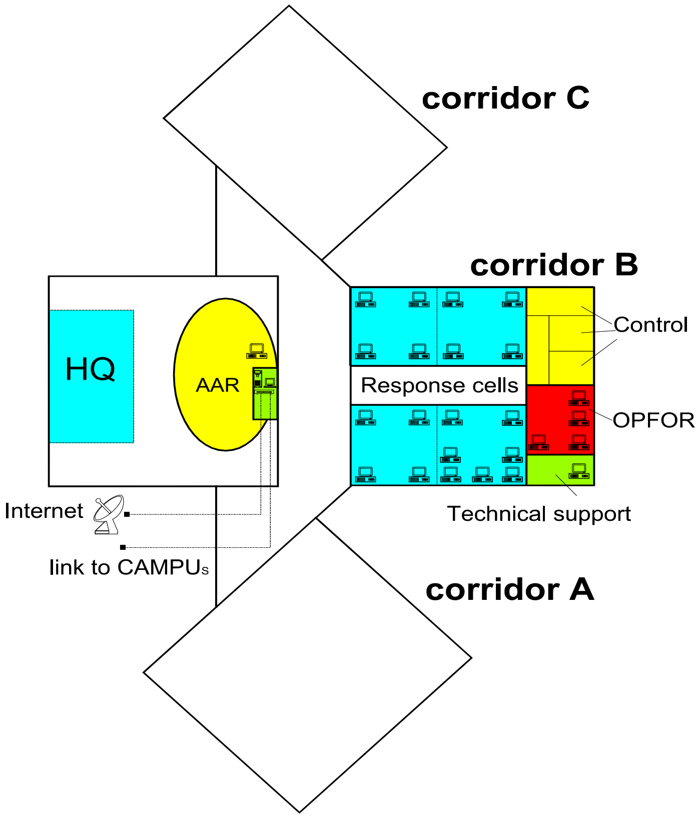

Figure 3: Facilities of the simulation center

SIMULATION SYSTEMS

In Slovenian simulation center two simulation models are used:

1. HORUS; to support exercises at the brigade level and above, and to support military operational research projects,
2. JANUS; to support exercises at the battalion level, and for the CAX for the peace support operations (PSO).

HORUS

HORUS is a simulation model, which represents the combined arms combat of the army. It essentially portrays command levels up to brigade/division level. The simulated elements are: armored units, infantry, artillery, army aviation, engineers, air defense, command and control, communication, logistics, and air attack sorties. HORUS was originally developed as an analysis tool. In this use, it allows to evaluate the impact of changes in terrain, force structure, equipment and operation plan to the outcome of combat in short time. By adding a multi user interface, HORUS was made also to support brigade/division frame exercises - CAX. HORUS is used for analysis within OR studies and as a tool for (mainly) brigade-level exercises. A further application in the area of mission preparation and support is possible (Knoll, 1999).

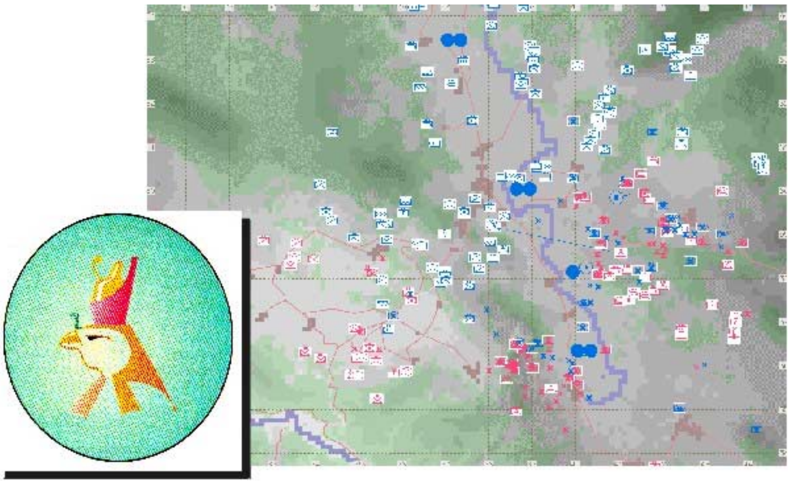

Figure 4: Typical screen of the HORUS simulation.

JANUS

JANUS is an interactive, entity-based, tactical simulation. It is six-sided, closed, stochastic ground combat simulation. It allows the planning and execution of tactical operations by up to six independent players, representing any mix of friendly, enemy, and neutral forces, none having knowledge of the other's intentions or actions beyond that provided in the tactical scenario or discovered in the course of the simulation run. Because of that, JANUS is essentially suitable for the CAX with the peace support scenario. It allows real time resolution of combat with live interaction between opponents, using realistic systems capabilities and limitations. JANUS is a relatively "user friendly" simulation, with a high degree of flexibility and adaptability to various training applications. While basic user skills can be learned fairly quickly, the sophistication of JANUS requires a degree of advanced expertise to gain full training value. (Cubic, 1996)

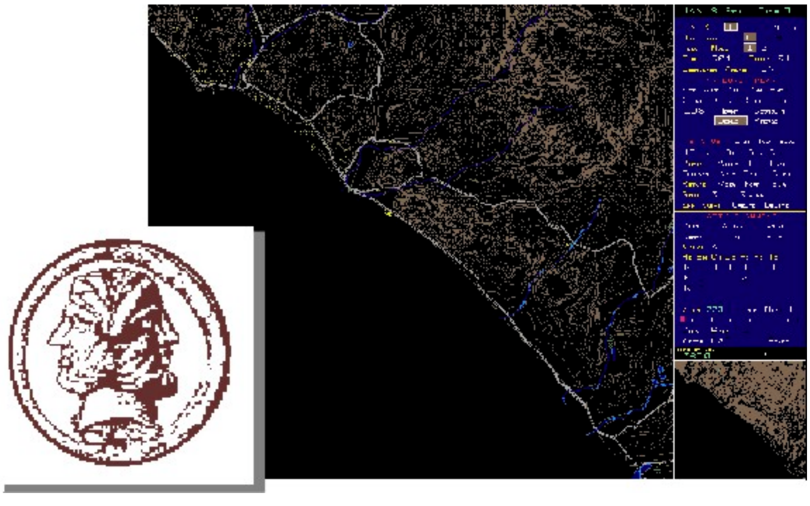

Figure 5: Typical screen of the JANUS simulation.

CONCLUSION AND VISION OF FURTHER DEVELOPMENT

Our biggest current concern is related to the improvement of the level of education and training in the military schools functioning within the framework of MEC and the level of training of Slovenian Armed Force units and commands. This objective can be fulfilled only through the establishment of a simulation center, where, using combat simulations, we are able to create such a real-life environment that offers military school candidates and commands training in tactics, operations and staff functions. In addition, individual commands are able to verify their combat plans on combat simulators and war game individual combat activities. Computer supported staff exercises represent the most modern form of training. Nowadays, many armed forces train at higher levels using exclusively this form of training in order to allow for the coordination of joint allied HQ work. Only certain exercise segments at lower levels are carried out "live". The development of a

simulation center is undoubtedly an important step towards adapting the Slovenian Armed Forces to modern military education and training standards. It is, therefore, no coincidence that the simulation center was organized as a constituent part of the MEC. Similar centers in other countries are primarily found in military educational institutions, where scientific and research work is given the equivalent support of teaching activities. However, we will not rest on our laurels. There are already new ideas and initiatives coming up. Based on the guidelines, given at SUMMIT'99, the Republic of Slovenia is joining the initiative to establish a PfP training center. In the following year we are going to launch an official initiative for the establishment of the PfP simulation center. This will open the center of the Slovenian Armed Forces also for the armed forces of NATO and PfP member countries. The simulation center has become the main actor of cooperation in war-gaming and simulations and a partner to NATO and PfP countries in the establishment of the international computer assisted training system. The establishment of the simulation center facilitates our integration into the PfP simulation network that will become a backbone of international cooperation in the area of education and training.

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L'outil d'entraînement d'états-majors au niveau opératif
Operative Level HQ Training Tool

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TENTATIVE TRADUCTION OF THE INTRODUCTION

Today, the main role of the conventional forces is to contribute keenly to the prevention, the limitation, or if necessary, the settlement using force, of the crisis and of the regional conflicts.

Forces must have the capabilities for the building up, the deployment and the support of joint task force, more often multinational, fitted to a mission and a theatre. These capabilities require a high interoperability level, which can be reached not only by linking together communication and working tools, but also by setting up of doctrines and procedures interoperable among themselves.

According to the joint M&S policy document, France decides to focus on the setting up of a HQ training system for the operative level, interoperable with the allied systems. This system, built too for the training of the executives, should be operational in 2003. The ALLIANCE project has been developed to reach this goal and will allow to elaborate the military characteristics of the future system.

Training assisted by computers allows to generate a common vision to the whole command post staff. It permits to make them interact at the right time and without risks, in order to co-ordinate the activities or to analyse the possible solutions to the current problems.

The preparation of the forces to the crisis management which is the main challenge, relies on the control of the environment and then on the technical control.

In order to fulfil this new type of preparation forces, the French computer assisted exercise concept is built on the STIMULATION and the SIMULATION. The operative level HQ training tool, based on this concept, must provide the capability to train the CJTF HQ and different component command (Land, Air, Maritime, Special Forces, Joint Logistic…) in real deployment conditions.

Firstly, the priorities focused in the joint M&S policy document will be mentioned.

Afterwards, the French simulation concept for the CJTF HQ training will be presented.

Lastly, the training tool dedicated to operative level training, based on the federation of distributed simulations and on environmental tools will be introduced.

INTRODUCTION

Aujourd'hui, le rôle principal des forces conventionnelles est de contribuer activement à la prévention, à la limitation ou, si nécessaire, au règlement par la force, des crises et des conflits régionaux.

Les armées doivent donc posséder les aptitudes nécessaires à la constitution, au déploiement et au soutien d'une force interarmées, le plus souvent multinationale, adaptée à une mission et à un théâtre donné. Ces aptitudes nécessitent un fort niveau d'interopérabilité, qui s'acquiert non seulement par l'existence de systèmes permettant de communiquer ou de travailler ensemble, mais également par la mise en œuvre de doctrines et de procédures interopérables entre elles.

Conformément au document de politique générale de la simulation interarmées, la France s'est fixée comme objectif de doter les armées d'un système d'entraînement d'états-majors au niveau opératif, interopérable avec les alliés. Ce système, bâti également pour la formation des cadres, devra être

Communication présentée lors de la conférence RTO NMSG sur « Défis futurs pour la modélisation et la simulation », au Pays-Bas, du 12 au 14 novembre 2001, et éditée dans RTO-MP-073.

opérationnel à partir de 2003. Dans ce cadre, le démonstrateur ALLIANCE[1] a été développé et va permettre d'élaborer la fiche de caractéristiques militaires du futur système.

L'entraînement assisté par ordinateur permet de générer une vision commune à l'ensemble des personnels d'un PC. Il permet de les faire interagir en temps utile et sans risques, afin de coordonner les activités ou d'étudier des solutions envisageables aux problèmes posés.

La préparation des forces à la gestion des crises qui constitue l'enjeu majeur, s'appuie d'abord sur la maîtrise de l'environnement et ensuite sur la maîtrise technique.

Pour répondre à ce nouveau type de préparation des forces, le concept d'entraînement assisté par ordinateur français s'appuie sur la STIMULATION et la SIMULATION. Le système d'entraînement d'états-majors au niveau opératif, basé sur ce concept, doit permettre l'entraînement du PC Force et des différentes composantes (Terre, Air, Mer, Opérations Spéciales, Logistique interarmées…) dans des conditions réelles de déploiement.

Dans un premier temps, il sera rappelé dans la présentation les priorités fixées par le document de politique générale de la simulation interarmées.

Il sera ensuite présenté le concept de simulation français mis en œuvre au profit du PC Force.

Enfin, l'outil d'entraînement dédié aux PC de niveau opératif, basé sur la fédération de simulations distribuées et sur des outils d'environnement sera présenté.

POLITIQUE GENERALE DE LA SIMULATION INTERARMEES : LES PRIORITES

Les aptitudes opérationnelles définies par le concept d'emploi des forces doivent permettre à ces dernières d'agir dans tous les cadres d'engagement possibles et de mettre en œuvre tous les modes d'action envisageables. Elles concernent la maîtrise de l'information, la participation au commandement d'une opération multinationale, la constitution d'une force, son déploiement et son soutien, le commandement d'un groupe de forces interarmées nationales ou multinationales.

Le document de politique générale de la simulation interarmées contribue activement à la satisfaction de ces objectifs de capacités opérationnelles, tant pour la conception et la planification que pour l'entraînement des forces, en respectant les priorités suivantes :

- **primordial** : contribuer de façon déterminante à donner à la France une capacité propre d'anticipation, de conception, de planification et de conduite d'opérations interarmées nationales ou multinationales, notamment comme nation cadre d'un PC Force.
- **important** : doter les armées d'un système d'entraînement d'états-majors au niveau opératif interopérable avec les alliés et contribuer à la formation des cadres.

L'engagement des forces françaises dans un cadre interallié fait partie du concept d'emploi. Ainsi, la préparation (notamment, la planification et l'entraînement de ces forces) doit être possible dans ce contexte interallié et interarmées.

Dans ce cadre, la simulation opérationnelle interarmées doit être interopérable avec les systèmes de simulation alliés, principalement au niveau opératif. Cette interopérabilité nécessite le respect des standards dans des domaines divers tels que les modèles de simulation, les données, les échanges avec les systèmes d'information opérationnels…

LE CONCEPT SIMULATION FRANÇAIS

Dans un environnement en pleine mutation (politique, médiatique, juridique, technologique…), la seule maîtrise des procédures opérationnelles n'est plus suffisante. La connaissance approfondie du théâtre d'opérations dans toutes ses dimensions, la maîtrise des cultures et des objectifs politico-militaires sont aujourd'hui indispensables pour assurer une gestion optimale de ces événements. A ce titre, l'informatique représente un apport primordial pour favoriser le transfert des connaissances opérationnelles et accélérer l'aptitude à conduire des opérations en particulier au niveau opératif.

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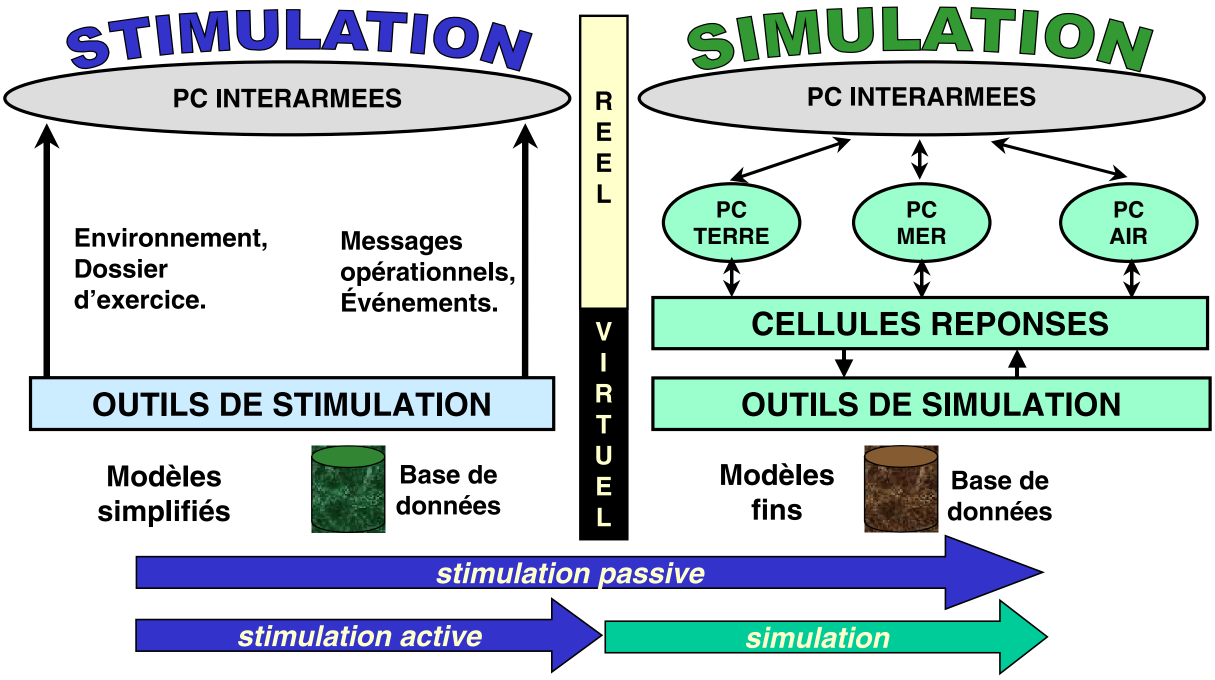
[1] Application LogicieLle InterArmées Nationale pour l'entraînement au Comandement d'un Engagement militaire.

Le concept de simulation interarmées français permet, au travers du CAX[2] l'entraînement à la prise de décision, à la pratique des procédures du PC, à la coordination des actions entre les différentes cellules d'un PC et entre PC. Pour ce faire, les modèles de simulation sont utilisés pour placer les commandants de forces, les états-majors, les systèmes de commandement et de conduite dans un environnement opérationnel réaliste.

Le schéma présenté, illustre, le concept CAX français mis en œuvre dans le cadre de l'exercice franco-britannique « Réaction Combinée 2000 » :



Le concept CAX se décline en deux phases :

- la **stimulation** : le but recherché est de former les différents acteurs, aussi rapidement que possible, à leurs fonctions au sein du PC, en vue de conduire les opérations liées à l'exercice ou à l'opération réelle. Cette phase s'articule autour de deux activités menées en parallèle :
  - la stimulation passive permet l'accélération du processus de transfert des connaissances opérationnelles (théâtre, ordre d'exercice, historique de la crise…). Cette activité est disponible durant la totalité de l'exercice ;
  - la stimulation active permet l'apprentissage de l'environnement opérationnel de travail.
- la **simulation** : le but recherché est d'entraîner le PC à la prise de décision et à la conduite d'opérations. Cette phase commence lorsque le PC est prêt à prendre le contrôle opérationnel de la crise. Il s'agit de conduire, via les cellules réponses, une animation cohérente du comportement humain et des systèmes d'armes en fonction d'un scénario politico-militaire. Cette phase s'adresse aux acteurs du processus de décision du PC à entraîner.

CAX = STIMULATION + SIMULATION

[2] Computer Assisted eXercise.

L'OUTIL D'ENTRAINEMENT

Caractéristiques principales

Le but est de disposer d'une capacité nationale de structure d'accueil d'un ensemble de systèmes de stimulation et de simulation, fédérés par l'utilisation du standard HLA[3], permettant l'entraînement, ou la participation à l'entraînement, des états-majors de niveau opératif nationaux[4] ou alliés (OTAN, européens).

Les données, échangées par fichiers ou disponibles au sein de bases de données partagées entre les outils utilisés dans le projet, seront élaborées selon le modèle de référence interarmées de l'OTAN.

Le système d'entraînement d'états-majors au niveau opératif sera constitué d'une plate-forme capable d'interopérer en local ou à distance, via des réseaux militaires ou civils, nationaux ou étrangers, et de manière cohérente avec :

- les outils de stimulation et de simulation nécessaires, existants et à venir de chacune des armées ;
- les outils de stimulation et de simulation nécessaires, existants et à venir chez nos alliés ;
- les outils destinés à la direction, la préparation et l'analyse après action de l'exercice ;
- les outils d'administration, de communication, de visualisation, d'impression, d'enregistrement et de restitution ;
- les systèmes d'information opérationnels nationaux (SICA, SICF, SIC 21, SCCOA…) ou alliés ;
- les outils permettant l'ouverture à un environnement enrichi : guichets cartographiques, guichet renseignement, serveurs d'information Web, informations météo… ;
- les outils de sécurité permettant de faire face aux menaces pesant sur les systèmes de communication mis en œuvre pour assurer les échanges entre les SIOC[5] et les stimulateurs/simulateurs.

Le système d'entraînement d'états-majors au niveau opératif est constitué principalement d'une fédération d'outils de simulation et d'outils d'environnement.

La fédération de simulations

Il s'agit de réaliser un système, basé sur une fédération HLA de simulations des armées, de niveau opératif. Les briques de base de ce système sont :

- WAGRAM[6] pour la composante terre :
  - permet d'entraîner un PC Force, un LCC de niveau corps d'armée ou division ;
  - niveau de modélisation des pions : bataillon / régiment, constitution en fonction de la mission de GTIA[7] spécifique, escadrille ALAT[8], batterie sol-air, PC de brigade, compagnie de génie, escadron logistique ;
  - agrégation au niveau brigade ;
  - natif HLA ;
  - génération automatique de messages opérationnels (AdatP 3) vers les SIC[9] ;

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[3] High Level Architecture.

[4] PC Force, PC de composantes (terre, air, mer, logistique, opérations spéciales…), ADCONFR, REPFR, CMO…

[5] Système d'Information Opérationnel et de Communications.

[6] WArGame terRe interArMées.

[7] Groupement Tactique Inter Armes

[8] Aviation Légère de l'Armée de Terre.

[9] Systèmes d'Information et de Communication.

- DUCTOR/ORQUE pour la composante mer :
  - permet d’entraîner un PC Force ou un MCC ;
  - niveau de modélisation des pions : bâtiment de surface ,sous-marin, aéronef ;
  - natif HLA ;
  - génération automatique de messages opérationnels (AdatP 3, OTH Gold) vers les SIC ;
- STRADIVARIUS pour la composante air :
  - permet d’entraîner un PC Force ou un JFACC ;
  - niveau de modélisation des pions : aéronef, base aérienne, centre de détection et de contrôle, réseaux, batterie sol-air ;
  - natif HLA ;
  - génération automatique de messages opérationnels (AdatP 3) vers les SIC, génération de la messagerie tactique (liaison de données tactique) ;
  - modélisation du combat sol-air, air-air et air-sol.

Ces outils de simulation permettent de couvrir les phases de stimulation et de simulation.

Les outils d’environnement

Par ailleurs, des outils d’environnement, développés dans le cadre du projet ALLIANCE, complètent les outils de simulation. Ils interviennent dans toutes les fonctions du CAX :

- la direction de l’exercice ;
- la préparation de l’exercice ;
- la conduite de l’exercice :
    - la **STIMULATION** ;
    - la **SIMULATION ;**
- l’Analyse Après Action (AAA).

Les paragraphes suivants décrivent les fonctions principales qui doivent se trouver dans le système d’entraînement d’états-majors au niveau opératif.

FONCTION DE DIRECTION D’EXERCICE

La fonction de direction d’exercice nécessite de disposer d’outils destinés à :

- définir les objectifs, le thème et l’organisation de l’exercice ;
- programmer la préparation de l’exercice et valider les données de cette phase ;
- conduire l’exécution de l’exercice et valider les événements et incidents injectés ;
- s’assurer de la cohérence de l’analyse après action et valider les résultats.

Les outils dédiés à cette fonction sont les suivants :

- le serveur Web de la direction d’exercice : cet outil assure le rôle de système d’information de la direction d’exercice ;
- outil d’appréciation de la situation : cet outil évalue les écarts avec la manœuvre prévue par le scénario pour alerter le directeur de l’exercice d’une éventuelle dérive vis-à-vis des objectifs recherchés.

FONCTION DE PREPARATION

La fonction de préparation d’exercice nécessite de disposer d’outils destinés à :

- gérer dynamiquement la disponibilité des outils de stimulation et de simulation liés à un exercice ;
- choisir les modèles de simulation ;

- participer à la genèse du scénario et des bases de données associées :
  - données pour le transfert des connaissances opérationnelles ;
  - scénario allégé pour la phase de stimulation ;
  - scénario complet pour la phase de simulation ;
  - données d'environnement.
- générer la liste des événements et des incidents MEL/MIL[10].

Les outils dédiés à cette fonction sont les suivants :

- outil de génération de scénario : cet outil, basé sur un travail collaboratif, est destiné à élaborer les différents documents de base relatifs à l'exercice (doctrine, concept, objectifs…), à construire le scénario et à définir le théâtre d'opérations ;
- serveur de diffusion de connaissances (SINACO) : cet outil est destiné à l'animation d'exercice comme support à l'administration de l'ensemble des documents préparés avant, pendant ou après l'exercice, ainsi qu'aux joueurs comme support au transfert des connaissances opérationnelles durant les phases de préparation et de déroulement du CAX.

FONCTION DE CONDUITE

La fonction de conduite nécessite de disposer d'outils destinés :

- au transfert des connaissances opérationnelles, grâce à la mise à disposition de la population entraînée, d'une bibliothèque[11] (stimulation passive) ;
- au transfert des connaissances opérationnelles, au travers du SIOC joueur (stimulation active) ;
- à l'entraînement proprement dit, du PC joueur, grâce aux outils de simulation.

Les outils dédiés à cette fonction sont les suivants :

- les simulateurs WAGRAM, DUCTOR/ORQUE, STRADIVARIUS décrits dans le paragraphe « La fédération de simulation » :
- outil de gestion des flux et de management HLA (GESTIM) : cet outil permet à la direction d'exercice de gérer le flux d'informations (messages opérationnels, messages d'incidents médiatiques) à destination des joueurs ou des cellules de réponse. Il permet en outre de gérer le fonctionnement de la fédération HLA (démarrage, arrêt, synchronisation, interactions entre les modèles…) ;
- outil de génération de messages opérationnels (TEMOIN) : cet outil permet, à partir de masques de saisie, l'édition de la messagerie opérationnelle au format AdatP 3 ;
- outil de génération d'événements médiatiques (SIMEDIA) : cet outil permet, à partir d'une base de données vidéo et sonore, de générer des messages d'incidents médiatiques type CNN ou dépêches AFP (vidéo, texte, son) ;
- outil de fusion (FLEURUS) : cet outil fusionne les informations issues de la stimulation ou de la simulation afin de constituer la situation interarmées. La présentation de la situation opérationnelle contient : la situation réelle, la situation perçue (par les forces alliées ou par les forces opposées) , la situation transmise.

FONCTION D'ANALYSE APRES ACTION

La fonction d'analyse après action vise trois objectifs :

- le recueil des données pertinentes relatives au déroulement du scénario et des observations effectuées ;

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[10] Main Events List/Main Incidents List.

[11] Cette bibliothèque, à titre indicatif, pourrait contenir des éléments relatifs à la nature des opérations, au théâtre d'opérations, à la structure de commandement, aux textes en vigueur, à des articles de presse, aux briefings (PC force, PC de composantes, etc.), aux glossaires…

- l’analyse des réactions des acteurs ;
- la synthèse des résultats de l’analyse pour tirer les enseignements indispensables sur :
  - la formation, la préparation des acteurs ;
  - les concepts, les doctrines et les procédures en vigueur ;
  - les SIOC en service ;
  - le système d’entraînement opératif ;
  - l’orientation à donner aux futurs exercices.

L’outil dédié à cette fonction est le suivant :

- outil d’analyse après action : cet outil, permet de tirer, à chaud ou à froid, les enseignements de l’entraînement du PC joueur relativement aux objectifs fixés initialement. Il est basé sur la mise en place marqueurs durant la phase de préparation d’exercice ou la phase de conduite et sur l’analyse d’indicateurs.

L’outil de transfert de connaissances (SINACO) est actif dans toutes les fonctions du CAX.

Toutes ces fonctions sont couvertes par des outils d’administration du réseau et des outils de sécurité qui protègent le système contre les tentatives d’intrusions.

CONCLUSION

Le prototype ALLIANCE a été mis en œuvre, au cours de l’année 2000, dans le cadre des exercices « Réaction Combinée 2000 » et « Rodage 2000 », pour démontrer la viabilité du concept CAX français.

Les principes directeurs qui guident le développement du système d’entraînement d’états-majors au niveau opératif sont les suivants :

- développer une structure d’accueil ouverte : standard HLA ;
- utiliser autant que possible l’existant ;
- placer les joueurs dans leur environnement opérationnel ;
- réduire la durée de préparation ;
- diminuer le volume des cellules réponse ;
- rechercher la cohérence avec les projets alliés (exemple, OTAN : PATHFINDER).

Le rôle principal des forces conventionnelles est de contribuer activement à la prévention, à la limitation ou, si nécessaire, au règlement par la force, des crises et des conflits régionaux. Ces missions peuvent se dérouler en agissant au sein de l’OTAN, de l’Union Européenne, d’une coalition ou éventuellement de façon autonome.

Compte tenu des missions assignées aux forces, l’entraînement assisté par ordinateur, doit permettre aux états-majors de niveau opératif, voire de niveau stratégique, de conforter les aptitudes leur permettant d’agir dans tous les cas d’engagements possibles et de mettre en œuvre tous les modes d’action envisageables actuellement.

Toutes ces aptitudes nécessitent un fort niveau d’interopérabilité, qui s’acquiert non seulement par l’existence de systèmes permettant de communiquer ou de travailler ensemble, mais également par la mise en œuvre de doctrines et de procédures interopérables entre elles.

Disposer d’un système d’entraînement d’états-majors au niveau opératif est un atout indispensable pour exercer des responsabilités dans la conduite d’opérations multinationales.

Enfin, il est prévu de mettre en œuvre ce système au cours de l’exercice national interarmées multiphases (OPERA) de 2001 – 2003.

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Improving Combat Dynamic Intuition – The Minimalist Approach

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Summary

This paper presents an approach to improve military commanders' operational training by focussing on combat dynamic intuition (CDI). CDI is the ability to intuitively comprehend what are the likely combined outcomes of the inherent dynamics governing the situation, and the decisions made to act upon the situation. In the first part of the paper we comment on current training practice (with its shortcomings), before we describe the minimalist concept for training higher-level commanders: based on simple, single-focus training models, running in compressed time on stand-alone PCs with small groups or even individuals as decision makers. In the second part of the paper we report from an experiment with minimalism in practice. Based on the experimental results, we point out directions for further research on the minimalist training concept. The experiment indicates that the "train as you fight" paradigm may need to be augmented by other paradigms as far as efficient commander training is concerned

Introduction

A typical military staff exercise, where a higher-level combat/conflict situation is simulated, requires considerable resources and takes days or weeks to conduct. Replays to see alternative outcomes are too costly. In this paper, we ask the question: Should decision making skills be built in a simplified/minimalist environment, *before* these skills are transferred to more complex, "sharp" situations ? This is seen in contrast to the way training is usually done – in real time and with high technological complexity underlying the increasingly available simulation support.

This paper reviews training of higher-level military commanders. This is then contrasted with the decision psychology in complex, dynamic environments. Discrepancies between current and recommended practice are discussed, and a novel approach to training in military settings proposed: The minimalist approach. Results from an experiment performed to investigate the appropriateness of minimalist training suggest that the learning process benefits from a minimalist training environment.

The training of higher-level commanders

The ability of senior commanders to make well-balanced decisions with appropriate degree of risk, in short time is often considered a key to operational success. It also appears that this ability reflects partly the "artistic" gift of the commander. He is to practice the *operational art*. Obviously the "artist" needs to learn and practice his trade. Traditionally this has been made through a training cocktail throughout the commander's career; historical studies, practical exercises (at increasing levels of command) and war-games have been regarded as helpful tools. Though one can argue about the role of innate abilities and skills that have to be developed, it is clear that training plays an important role in the development of a good commander.

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The need for a new training paradigm

Things appear to happen with regard to the cocktail of tools. This has partly to do with emerging doctrinal issues, and partly with technology developments – and they are interrelated. It used to be that an operational level commander would command single service units of national capabilities. Current operations, however, are joint and combined at increasingly lower levels of command. They are also multinational at ever-lower levels of command (the special forces likely to be used in Afghanistan in the fall of 2001 are but one example). This has implications for training in that the typical single service training previously so critical for the operational commander no longer is sufficient. Not that the single service training is less important – on the contrary – increased op-tempo and technical sophistication combined with delegation makes it ever more important to understand the operational dynamic implications on single service combat or crisis decisions. But in addition, more understanding is needed about similar implications of decision making on complementary service operations.

Furthermore, the commander must not only understand the dynamics of combat, but also the dynamical implications on other operations. On top of that, the decision maker needs to be able to integrate more factors in a shorter time than before – at least if he wants to out-cycle the enemy by eliminating a bottle-neck in today's operations – time required for decision-making. This again fuels a need for a decision maker that is able to quickly think through – or even better, intuit – the effects of actions taken. The proliferation of decision supports tools makes the demand for intuitive decision making only stronger, as such intuition also must guide in the selection amongst a plethora of information sources.

The combined effect of increased doctrinal, technological and operational complexity is a virtual explosion in the need for commander training. This explosion can clearly not be only met with increased real life exercising. Similarly, war gaming and historical analysis appear to offer training with obvious and severe limitations.

The mainstream approach to training

An operational HQ typically employs hundreds of people. To simplify, most of the officers act as information gatherers, human data "fusioners" and filters, or they support such filtering. Most exercises then are not aimed at training decision making, but at training the procedures required to get the information filtering and dissemination "machine" – that is, a HQ – to work.

Typically, simulation is used to generate sensible dynamics of, and information about, how a combat or crisis evolves over time. Drivers for these dynamics are increasingly synthetic units that again feed the C4I systems in the HQ. Both synthetic enemy and related "foreign" units and forces that are on "our side" act upon the orders and information given via the same C4I system.

Over the last decade, new computer information architecture under the heading "High Level Architecture" (HLA) has availed the running of various virtual operations on separate computers. This has proposed two interesting computer related challenges to the technology community: (1) coordination of various detailed lower level units, and (2) incorporating physical and virtual units into the one and same exercise.

Much National and NATO development activity is aimed at achieving HLA compliant simulations in support of command and staff training. The total development cost within the alliance today is probably in the two-figure billion-dollar range. The technology challenges are many, and typically these development activities are subject to the rule of pi; the relationship between initial cost and time estimates, and final cost and development time spent, is 3.14 at best.

Shortfalls in the mainstream approach

Even if they were available today, in full compliance with specifications, and for free, these HLA oriented solutions will fall short of a requirement to answer the needs for training tomorrow's commanders and decision makers.

First: The requirements. It appears clear that decision training should focus on the relevant factors for training a successful decision maker. A key to achieving effective learning is a two-step feedback. The first step is to see the consequences of ones own actions in a meaningful way. The second is an evaluation of those results.

There are two types of feedback consequences for a commander. Those relating to how he is perceived by his supporting staff (including his tactical commanders) and those relating to how the adversaries respond. A question relating to the first is how the subordinate staff and commanders understand and carry out the decisions outlined by the commander. This is usually the key issue in staff procedure training. Current mainstream M&S efforts address this issue well.

The other key feedback deals with the feedback from the field; are the decisions coordinated so that logistics and operating units are in synch – and if so, are the field objectives obtained – the rogues under control, the battle won or avoided, the campaign successful? To achieve meaningful feedback for such purposes, the time span of the exercise must be appropriate. Typically the relevant time horizon increase with the command level. For a tank commander the focus should be on the next minute, hour or day. For the CJTF commander, this should typically be the winning – or carrying out – of the current campaign. Typically, then, feedback can only make sense after a week, a month, or a quarter of a year.

The above logic suggests that there are competing and incompatible demands on the training of commanders. To train the format of decisions – i.e., improving the staff organization's processing of information embedding a decision – then training must be done in one way. To train the content of the decision, training must be done very differently.

From the above it follows that training decision making in the context of feedback about adequacy of decision *formats*, real time is the maximum speed with which the training can proceed. Achieving *real time* is the requirement for such training.

However, training decision *content* requires substantial time compression. Typically, a thirty day campaign is played within a day or two, and so the clock in the training room must go ten to a hundred times faster than in the real world. Achieving time *compression* of at least factor ten is a requirement for this type of training.

Another requirement relates to the need to support faster decision-making. In essence, a commander needs to think fast. This again requires both that his conscious reflection be fast, but also that the tacit cognitive rules underlying his decisions be fast and accurate. Both the former reflection and the latter sub-conscious processes are subject to improvement through better intuition.

Psychological studies have shown that such intuition indeed may be refined, and furthermore that it requires massive training (Sterman, 2000; Bakken, 1993). This need for massive training is especially pronounced if un-learning needs to take place. A typical case of needing to un-learn is when prior and lower level training is at odds with the principles of decisions at higher level. Since un-learning is harder with age and domain experience, massive efforts are especially needed for the very experienced cadets that attend senior staff colleges, and even more so for senior commanders.

In training and exercise parlance, massive training implies that scenarios should be run through not once, but preferably dozens of times. As a consequence, training professionals in the USMC use the analogy from rifle training applied to the refinement of senior officer mental models and intuition, labelling their concept with the metaphor "a shooting range for the mind". Similarly, training events should not happen only once every four or five years, but several times a year. Large staff exercises, especially if multinational, typically require years of pre-planning and total immersion for hundreds of people. There is no practical way for such exercises to be carried out with the required frequency.

In sum, there is really no way of satisfying the need for decision format and decision content training simultaneously. The one requires real time, and the other requires substantial compression. HLA developments – at least where several levels of commander input is required, may be an appropriate way to achieve training in decision format and procedure, but is not suited for the content training for the reasons stated.

The minimalist approach to decision training

A minimalist decision trainer is a very simple and pedagogically designed simulation-supported system for use in the training of higher-level commanders (both existing and to-be). The training focus is to build and rehearse the commander's ability to quickly form a mental image of a combat/conflict situation, and to intuitively comprehend what are the likely combined outcomes of the inherent dynamics governing the situation, and the decisions made to act upon the situation. This ability is required when it comes to making rapid decisions of high quality – essential for achieving success in (over-)complex and "dramatic" situations. A commander who has this ability can be said to possess *combat dynamic intuition (CDI)*.

The concept of CDI is closely related to the concept of *tacit reasoning* and *implicit memory*, which has been studied by cognitive psychology researchers (see e.g. Broadbent et al. 1986). Implicit *learning* focuses on learning in (fairly complex) situations where the learning is not necessarily the (primary) intention, and where the resulting knowledge may be difficult to express.

Choosing a term such as "minimalist" to describe this novel approach refers to that the training system should contain no unnecessary elements or ornaments. Unnecessary elements have the disadvantage that they take up space; they induce costs and detract energy from the designer, the builder and the user. In other words, minimalist design is a special form of functional, no-frills and focused design.

In contrast to much of current high-level training developments, minimalist training does not have a technology focus. There is no a priori requirement that it be synchronized with current C4I facilities, no requirement that one should "train as you fight", nor that the simulation technology should be used to design synthetic actors and units so that they mimic real ones as realistic as technologically possible.

On the contrary, the requirements derived above for training the decision content prevail, with one major addition. When commanders from various nations and services operate, they need to be in tune. For the bulk of staff officers, this tuning requires that procedures be transparent and common – or commonly understood. More importantly however, mental models of decision makers need to work in harmony. This again is an argument in support of massive training, preferably in small groups allowing discussions and sharing of mental models. It further underlines the requirement that staff and commander training be done asynchronously, i.e., coordination must be reflected in the training program design, not within the single exercise.

Minimalist decision training (MDT) belongs to a class of training solutions referred to as "Management Flight Simulators" (MFS) – a term invented at MIT's Sloan School of Management (Bakken et al., 1992). Instead of individuals flying a simulated aircraft, a management team "flies" the corporation, creating products that "fly in the marketplace" through making appropriate strategic, operational and tactical decisions. MDT represent the best of tabletop war games and MFS for its players: An operational level commander – or more typical – his associated command group.

MDT is aimed at putting a commander or the command group in charge of own logistics and operations resources in a scenario. The scenario may contain any implied or explicit mission. The resources reflect a combined joint operation; typically the lower limit of resources will be less than a hundred units representing land, sea and air resources, with upper limit being less than a thousand.

At a more concrete level, the features that discern the minimalist approach from other ("maximalist") modes of training, can be grouped into aspects concerning technology, model and training objective.

Technological minimalism: By allowing the "train as you fight" rule to be broken, there is no need to integrate a simulator with active C4I systems. By not requiring every combat platform or even higher-level physical unit to be included in the simulation, a simpler simulation technology may be used. This again ensures low hardware requirements; they are met with a laptop computer. Software costs are reduced to a small fraction of what is commonly associated with staff training development efforts.

Model minimalism: Rather than designing a comprehensive system that may be used for all training purposes, the MDT represents a suite of smaller models, each with a specific training objective in mind. By including operational insight in the design, the simulation model becomes understandable to the training audience. Furthermore, this enables the required time compression, ease of use and low cost. Typically a suite of a dozen models will suffice for any user group (current or prospective commanders, and the personnel supporting those commanders). Again the development effort is reduced to 12 times the average model, rather than its 12th power if the requirement is that the models shall be integrated run-time.

Minimalism in the training objective: Typically a HQ exercise has a host of objectives that should be fulfilled. The creating of an integrated team spirit and "sense-making" of the entire HQ is often over-arching. In MDT, on the contrary, there is no ambition to support such "feel-good" objectives. Not that such objectives are unimportant – which they certainly are. But the MDT only purports to support the development of better intuition of what happens in the field – outside the HQ. The dynamics of the HQ itself can be achieved in a variety of ways – but they all interfere with the MDT objectives. MDT also reduces the size of a typical required support team to the size of the command group itself. The cost and scheduling advantages of this are obvious and indeed a requirement derived from the "shooting range for the mind" ideas.

MDT in action: An experiment

In order to investigate the validity of the above logic, an experiment was carried out. The experiment can be regarded in two ways: (1) as a way to test whether extreme simplification can be carried out in practice; and (2) as a vehicle for determining how to adjust critical pedagogical parameters – given that MDT is found to be a valid concept.

In the experiment we varied the task complexity along two dimensions: Simulation model complexity and cover story complexity. The model simulated a humanitarian task, where decision makers were either in command of an operational supply chain; a supporting supply chain; or had to control both in combination. Practice on the simulation model was organised at two levels of complexity: Practice on each of the single supply lines in turn, before embarking on the combined task (simplified, decomposed approach); and as practice on the combined task from the start (full-scale, combined approach). Similarly the cover stories existed in two versions – a very brief one – and a more verbose one (more than twice the number of words compared to the former).

When practicing, the decision makers were instructed to complete as many trials as they could manage within a limited time – 100 minutes. The time limit was equal across all treatments.

The effect of practicing was measured as performance on a subsequent evaluation task – similar to the full-scale task with verbose cover story, but with slightly adjusted contextual information. The null-hypothesis reflected common "train as you fight"-pedagogy – i.e., that interacting with the training task closest to the evaluation task would give the highest "real" performance.

Results and implications

A total of 84 persons from local military academies and a business school participated in the experiment. The table below shows performance across treatments. The performance index is quoted in *percent* (standard deviations in parentheses) of average performance. For further details on the experimental procedure and results, see Bakken et al. (2001).

Performance		Simulation model		
Cover story		Simplified	Full-scale	*Mean**
	Brief	108 (25)	103 (29)	*105.5*
	Verbose	93 (46)	96 (36)	*94.5*
	Mean	*100.5*	*99.5*	***100***

Table 1: Performance across treatments ** P = 0.15*

We see from the table that the null hypothesis may be discarded. In fact, the effects are the opposite. It appears that the simpler cover story (that is, the one farthest away from the "real" situation) gives arise to the highest performance (P=0.15). Similarly, though there is no general effect on training effectiveness of decomposing during the practice session, it appears that the combination of brief context and simplified "learning" model is conducive to training. However, since the relationship between model simplicity and performance is reversed for the verbose context case, the model simplicity cannot be regarded as a key to training effectiveness. There appears to be an intervening variable.

We therefore also compared performances on an individual level, and found that the best performers are those who manage to complete the most practice trials. The table below shows that there is a significant difference in performance (P=0.04) when comparing the top and bottom 25% intensity players. Furthermore, significantly more of the practice trials occur in the low complexity treatment groups, with nearly 50% more trials completed in the simplified model/brief story treatment as compared to the full-scale/verbose group.

Intensity and performance	Trials	Performance**
Top 25% in playing intensity	50 (7)	110 (22)
Bottom 25% in playing intensity	14 (4)	90 (36)

Table 2: Intensity extremes and corresponding performances

*** P = 0.04*

To sum up, we find that the number of practice trials explains performance, not the treatments as such. But there is a reverse relationship between the "train as you fight" idea and factors that enable more trials. A key training issue then becomes how can such increased training frequency be obtained in practice. The experiment indicates that a simpler cover story, and a simpler simulation model will not in itself be sufficient. It appears that participants have a "natural" rhythm of decision making. If the cognitive complexity is decreased through a simpler cover story or a decomposed model structure, participants to some extent *compensate* by creating thinking and reflecting on additional hypotheses about cause and effect relationships. Creating a minimalist decision environment appears to be a required, but not sufficient condition for acquiring combat dynamic intuition; there needs to be a conscious pedagogical program around any significant decision compression effort.

Conclusions

Effective training of commanders is a task that lends itself well to computer simulation. With the advent of increasing computing power has come a development of ever more sophisticated and interoperable virtual learning environments. Especially for training at the operational level, simulations may integrate dozens of models and typically cost hundreds of million dollars to develop. Yet, their inherent complexity – though critical in enabling coordinated operational staff and tactical decision training – are at odds with the goal of training the operational commander.

A key feature of effective training in combat and crisis decision-making is high exercise frequency. Another requirement is that the decision maker to see the consequences – good or bad- of his/her decisions. Both aspects require time compression in the simulation. This is made practically impossible if operational staff and tactical commanders are to be co-trained with operational commanders. Supporting staff need to exercise in close to or real time.

Minimalist decision training (MDT) is characterized by simplifying the commander's operating environment, compressing time and space. By specifically separating, but coordinating, command and staff/lower level training, a typical three day exercise can cover thirty days of conflict and at the same time give continuous feedback about the unfolding of the conflict consequential to decisions made.

We tested a prototypical MDT system empirically, and found that subjects' performance increased with number of practice trials, even if the total training time was fixed. The supporting pedagogical program should

include elements that intensify the training process (i.e., stimulates a greater number of practice trials in the same amount of time). This again requires the training environment to be kept sufficiently simple.

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From Legacy Simulation to Interoperable Distributed Simulation: Alenia Aeronautics Experience

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SUMMARY

In recent years, a growing need for distributed simulation systems has arisen. This has brought a great challenge to the Modelling & Simulation community, in terms of new interoperability issues and problems related to the reuse of legacy simulators.

The issue is undoubtedly a very complex one, so much so that the entire HLA technology (High Level Architecture) has been developed to specifically address these problems, and meet the many challenges posed by distributed simulations. Alenia is evaluating this technology, and integrating it within their Flight Simulation department.

This paper describes activities carried out at Alenia Aeronautica to demonstrate technical feasibility, as well as planned development towards a systematic use of this novel architecture. In view of growing requirements and to anticipate future demands, Alenia is also working towards the extension of their Synthetic Environment to geographically separated, external simulation facilities.

INTRODUCTION

The aircraft design process followed by Alenia Aeronautica is supported by simulation since 1961. At the beginning, analogue computers allowed to apply simulation for quickly assessing aircraft performance and for performing trade off during system and subsystem development. The availability of more powerful digital computers, visual systems and high fidelity Human-Machine Interfaces permitted, over subsequent years, to expand simulation scopes by including whole aircraft system development and test, aircrew conversion-to-type and mission training.

Today, the continuous improvement of hardware and software performance permits to connect different simulations and systems over geographically distributed networks to attain a virtual space, i.e. a Synthetic Environment, within which to design highly complex weapon systems , to train pilots in a multi-ship and multi-side “operational representative environment” and to rehearse real-life operations. This evolution therefore lays the foundations on available proprietary systems, and while there is room for further enhancements, a number of issues which are far from trivial have yet to be solved.

This paper illustrates at first the simulation facilities operated by the Systems and Simulation Department of Alenia Aeronautica. Steps taken by Alenia Aeronautica to reach a distributed simulation capability and towards the future exploitation of a company Synthetic Environment are also described. The adoption of the existing LAN Ethernet link and a customised Distributed Interactive Simulation (DIS) data exchange protocol has allowed the achievement of on-site distributed simulation. The department external interoperability is currently under accomplishment through a dedicated front-end based on the novel High Level Architecture (HLA) standard. Some concrete examples of Alenia's commitment toward the development of a Synthetic Environment are then described. Finally, noteworthy issues encountered during development and currently foreseen are highlighted and briefly explained.

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SIMULATION FACILITIES AT ALENIA AERONAUTICA

The Simulation Department of Alenia Aeronautica currently operates four flight simulators: Eurofighter "Typhoon" in two versions, development and production standard, the C-27J "Spartan" tactical transport aircraft and the AM-X ground attack aircraft.

Figures 1 and 2 show the Eurofighter development and production flight simulators, respectively. The former has a visual system which is also based on a GE CompuScene IV with three background projectors and one dual-target projector, and runs on a Digital Alpha host computer, while the latter is based on SGI machines and sports a fully integrated Equipe Electronics “Blue Sky” visual system. Based on a five pipe SGI Onyx2 “Infinite Reality2” image generator, and covering the pilot's entire field of view, this system also includes two high-performance target projectors for high-resolution visualisation of mobile targets, to be used for dogfight simulations. This simulator is characterised by a fully representative cockpit, placed within the 6-meter diameter rigid dome.

Figure 1 – Eurofighter development simulator

Figure 2 – Eurofighter production simulator

Figure 3 shows the two-man glass cockpit of the C-27J simulator which is constituted by a mix of actual production and ergonomically/functionally representative hardware/instrumentation built for flight simulation purposes. The image generator of this simulator includes an Equipe Electronics "Blue Sky" visual system based on SGI "Infinite Reality2", and three SEOS-modified Barco projectors fitted to a “Panorama” display system. The image of the outside world is collimated for both pilot and co-pilot, thus enabling an adequate field of view from both seats. A three-axes, five-channel Fokker Control Loading System is used for the modelling of the forces on flight controls in every operational setting. The C-27J Simulator is presently used to support the development and flight test activities, and has also been conceived for training of the aircrew of the customer Air Forces. As a consequence, it is going to be equipped with an on-board instructor station, located behind the cockpit.

The AM-X simulator, initially built to support the aircraft development, has also been used for initial training of more than one hundred Italian and Brazilian Air Forces pilots between 1989 and 1993. The asset is based on a Digital Alpha host computer and is set up inside a dome (figure 4 shows an external view of the simulator). The image generator consist of a GE CompuScene IV and three scenario projectors. This simulator is being upgraded to be used in supporting development of new updated versions of the AM-X.

Figure 3 – Internal view of C-27J simulator

Figure 4 – AM-X simulator

In addition to the above full flight simulators, a number of assets are available to support the simulation department activities: an Eurofighter "Typhoon" Aircrew Cockpit Procedures Trainer (ACPT - figure 5), the tactical scenario visualisation and Computer Generated Force tools (CGF) (figure 6) and the so-called Stereoscopic Table (figure 7).

The ACPT was conceived as a low-cost, flexible system allowing pilots familiarisation with cockpit procedures before flight simulation sessions. The station includes basic flight controls, three flat touch-screen displays as HMI and a proper software suite allowing to represent aeromechanical as well as aircraft systems behaviour. The ACPT, which is due to be completed soon, runs on a simplified version of the Eurofighter production simulator database.

The tactical scenario visualisation and CGF tools generate many independent actors, i.e. aircraft models, which are based on a simplified aeromechanical model and operate according to a customisable behaviour. The scenario, which runs on a dual-processor SGI Onyx2, can also contain any full flight simulator component, as far as position and status are concerned. The observer's point of view can be chosen at will and can be presented on screen either as a two-dimensional map or as a three-dimensional view. In this case target lines and trajectories can be visualised to help the observer perceiving/assessing complex manoeuvres.

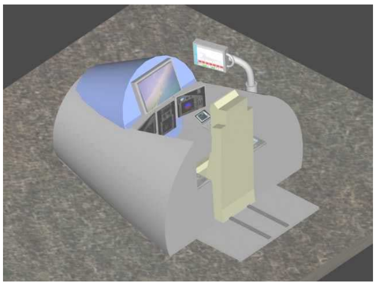

Figure 5 – Artist’s impression of the ACPT

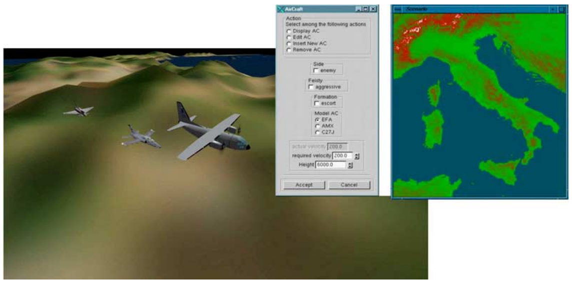

Figure 6 – Snapshots from the CGF tool

The third tool, i.e. the Stereoscopic Table, is a tiltable 67" rear-projected CRT-based monitor. With a pair of positionally tracked special LCD shutter glasses, a stereoscopic image can be displayed with flicker-free refresh rates. The system, which runs a proprietary visualisation software, is mainly used as a mission briefing and debriefing by way of a three-dimensional “God's eye” view of a previously recorded flight. Thanks to the flexibility of the visualisation software, the scopes of applications are planned to widen, comprehending white force port during distributed simulation sessions, mission planning and rapid cockpit prototyping.

Figure 7 – The stereoscopic visualisation table

In short, available assets are legacy systems which were developed in-house and subsequently maintained to support the aircraft design process. Up to date and future flying systems require the availability of an integrated Synthetic Environment which apply to the entire life of the product, starting from design and acquisition, to operation training and, finally, to live operation optimisation and rehearsal.

Given the importance of such an environment and the experiences already available, Alenia Aeronautica have elaborated and started an incremental three phase development plan, consisting of:

1. Achievement of on-site interoperability
2. Achievement of external interoperability
3. Exploitation of a Company-wide Synthetic Environment

The following paragraph will highlight this plan.

ON-SITE INTEROPERABILITY: THE ETHERNET LINK

Local interoperability has been achieved through a number of steps including the implementation of the Eurofighter twin dome facility, the link between the C-27J simulator and the AM-X simulator and the exploitation of local distributed simulation through the Ethernet based LAN.

The twin dome facility has been developed in order to in order to enable an air-to air training capability. The two Eurofighter simulators were linked by a VME-based reflective memory, i.e. a high-speed optical link. Due to the incremental upgrade of existing simulators, all components of the Eurofighter production simulator are part of the loop, whereas some important element of the Eurofighter development simulator remain on the local Ethernet LAN. This solution does not have an impact on the efficient mutual data exchange between the two assets and remains, in our opinion, a very efficient and cost-effective method to share information and memory segments at a local level. Within this loop the CGF is also available, providing appropriate representation of a tactical air-to-air scenario.

A similar architecture is also deployed in another optical loop, connecting the elements of the C-27J simulator. By including in this loop the host computer for the older AM-X simulator, a direct data exchange between the two is possible, therefore enabling formation flights.

One of the main issues that has been faced during above integration was the adaptation of each asset's geographic database. In fact, the Data Base Generation System (DBGS) and the Image Generator (IG) of older simulators were developed, integrated and optimised in a proprietary solution. Even if available databases referred to equivalent elevation models, differences in Earth reference models and IG computing algorithm make the problem became apparent (some scenario inconsistencies and different details available in different scenarios representing the same geographic area). Specific solutions have been developed by tackling both proper position conversion, to attain consistency, and scenario ad-hoc population to increase flight fairness. Although research activities aiming at the development of algorithms to convert data from old proprietary formats into sharable formats are under execution all over the world (e.g. the SEDRIS project), the problem still has not found a broad-spectrum solution.

Bearing in mind the first phase objective of achieving full integration amongst the facilities previously described, an architecture such as shown in figure 11 has been put in place. A central 10Mbps Ethernet switch provides a common infrastructure for all the assets to communicate with each other, by broadcasting each its own status and position data according to an adaptation of DIS protocol, and each receiving on dedicated Ethernet ports the information pertaining to the rest of the simulators, ACPT and all the CGF synthetic actors pool. This link is less efficient than the optical loops, in terms of latency and reliability of the data transfer, but has been shown capable to support real-time interactions and a steady data flow. Compensation for these limitations is provided by extrapolation: this technique must also be employed because of the diverse frame rates, specific to each simulator.

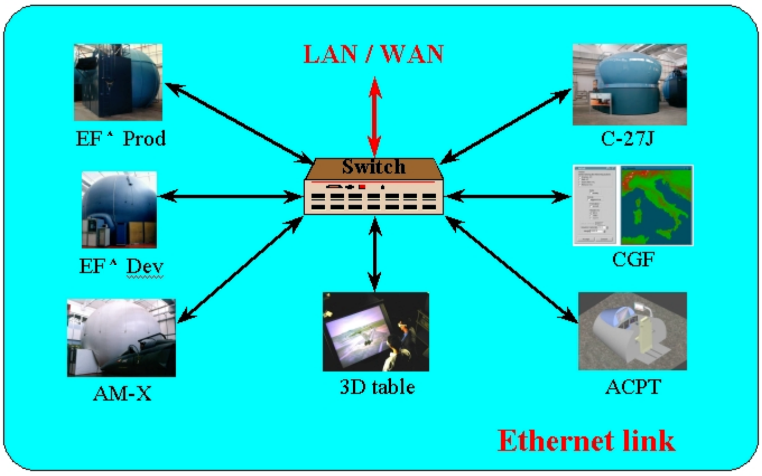

Figure 11 – Ethernet configuration of Alenia Aeronautica simulator department

This solution has several advantages: low cost, ease of implementation, and well-tested backbone protocol (TCP/IP). In addition, it enables quick and agile inclusion of any other asset in the LAN Ethernet link.

The accomplishment of geographical distributed simulation could also be possible by using a high-speed Wide Area Network (WAN) link architecture. However, the above solution is optimised for the specific configuration of the Simulation Department; therefore a different approach, considering the High Level Architecture, has been followed.

EXTERNAL INTEROPERABILITY: HIGH LEVEL ARCHITECTURE

After distributed simulation applications have proven to be feasible, the need for standardisation of the solutions adopted become evident. As requirements and simulation complexity have grown, available methodologies, including Aggregate Level Simulation Protocol (ALSP) and DIS, revealed a number of constraints. Referring to those experiences, a very successful architecture, named High Level Architecture (HLA) was defined. Firstly developed by the U.S. Defence Modelling and Simulation Office, HLA has quickly gained momentum both for defence application and in civilian circles. Some five years after it was first defined, HLA has achieved the status of IEEE standard and in 1998 has been included in the NATO Modelling & Simulation Master Plan as a sub-objective of the development plan ("Adopt the High Level Architecture as the NATO standard technical architecture for simulation applications").

For these reasons, with HLA is being sought all around the Simulation community and so has been considered for experimentation within the Simulation Department of Alenia Aeronautica.

A new optical link of a type similar to existing ones is planned, so to connect in a ring all four simulators, the ACPT, and the CGF/scenario visualisation tool. In addition, a dedicated machine is going to be included, which will be dedicated to HLA software. It will run the Run Time Interface, the basic infrastructure allowing to implement the HLA standard, and it will host the HLA application responsible for representing the federate constituted by all entities connected by the ring. Its tasks will include publishing status data to the outside, subscribing to services available outside of the department, and providing a software layer to use for external interaction, according to the specifications of HLA.

This is necessary since all legacy simulators would require excessive modifications to be able to cope with an ad-hoc HLA front-end.

A reflective memory ring on the inside, and a single federate HLA front-end on the outside seems to be a more satisfactory solution than having several HLA front-ends (one for each simulator) all communicating independently with the RTI. In those cases in which the HLA services are required also within our federate, a single-simulator front-end can be run as required on the same dedicated machine, which continues to see all the simulators through the same reflective memory. This solution (figure 12) has the advantage of not increasing the computational workload of any simulator, while still providing a dedicated HLA front-end.

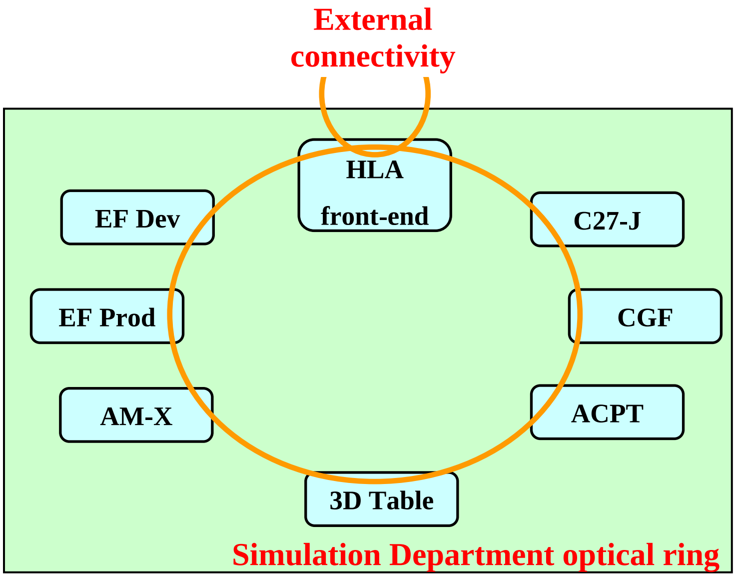

Figure 12 – Optical ring connecting the entire department into a single HLA federate

The development of one front-end is aimed at minimising the risk of inefficiencies that may result from introduction of HLA within the department.

- Different data structure addressed by HLA – Object Oriented – and legacy simulations – structured programming.
- Need of expertise in both legacy systems architecture and new technologies/paradigms with a proper “system oriented” view.

Additionally, at the present stage of development, the use of DMSO-provided software might imply complications in that it has been developed with the aim of providing the users community with a workable, non-optimised mean to implement HLA. Therefore RTI performances have to be optimised towards each specific federation, either by trials or with automatic tools. The HLA software has been already written and tested, but still needs to be integrated with the optical link hardware.

A further issue that has been considered during the above activities is compliance with security measures. In this respect, on-site interoperability is possible according to Company policy and national security regulations. External connectivity is possible as far as it is authorised by competent agencies.

TOWARDS A COMPANY-WIDE SYNTHETIC ENVIRONMENT

The seminal distributed environment described above is the kernel of a company-wide initiative encompassing tighter co-operation bonds between all departments in charge of the product design, i.e. weapon system design. Referring to the previously described development plan, the third phase consists in the exploitation of a company Synthetic Environment (SE); this is intended as a pool of models, simulations, real equipment, with human actors in the loop, operating into a common virtual representation of the world. In this respect, consistency and concurrency are provided to groups of previously detached processes. This environment enables the visualisation of complex military systems behaviour (also considering changes to the systems or to their operating environment), and provides

powerful means of communication between and within teams, especially where concurrent system development is taking place.

The vision that would serve as a reference to attain a company SE comprises three main outposts (figure 10):

- Operations: this area comprises organisational matters, functions and roles definition.
- Systems: Hardware and Software infrastructure to support the activities as identified in the Operations area.
- Methodologies: standards, rules and recommended practices (applicable at international, government and company level) which has to be followed for appropriate work of the SE.

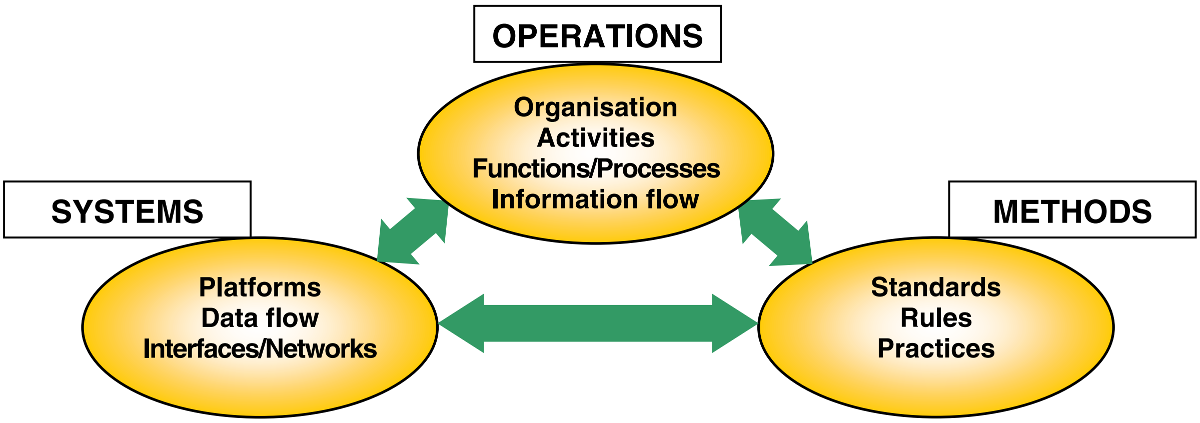

Figure 10 - Synthetic Environment outposts

The introduction of the above architecture would imply a number of advantages:

- Improvement of the product quality and in-service support.
- Overall reduction of product life-cycle costs.
- Enhancement of the production process in terms of interfaces both inside the company and with Suppliers and with the Customer.

On the other hand, some issues could weaken or slow down the development of the above structure. One significant issue is cost: as a matter of fact, setting up of the above organisation requires massive investments in terms of infrastructures, systems and human resources. It is therefore evident that the introduction of a company SE requires balanced evaluation and an iterative development.

While considering the above obstacles, evaluation of proper ways to further develop the vision is carried out through a number of activities, namely the European Commission-funded project ENHANCE and the WEAG Research and Technology Project (RTP) 11.13.

- ENHANCE (Enhanced Aeronautical Concurrent Engineering) is a wide scope 3-year duration research project supported by the European Commission which started in February 1999 within the activities of the 4th Research Framework Programme. The main objectives of the project are to: reduce the time-to-market, reduce the development cost and reduce the data management, conversion and transmission cost of European Aeronautical product development. Main focus of the project is on product engineering and design in an extended enterprise concept but there is activity devoted to product support, certification, contracts and multi-site teamworking. Results include common processes, methods and tools to be used and exploited not only by the project partners themselves but also by the Supply Chain to improve Concurrent Engineering practice for all levels of the Aeronautical Supply Chain. These take the form of 'Demonstrators' that show how these common processes, methods and tools meet their respective target requirements in terms of time, cost and quality.

- RTP11.13 “Realising the Potential of Networked Simulation in Europe” is a Western European Armament Group-funded project developed within Common Eropean Priority Area 11 (CEPA) “Defence Modelling & Simulation Technologies”. The project, which refers to the European Cooperation for the Long-term In Defence (EUCLID) framework and involves 22 companies from 13 European nations, started in November 2000 and has a duration of 36 months. The main goal of the program is to overcome the obstacles that prevent SE from being exploited in Europe, by developing a process and an integrated set of prototype tools intended to reduce the cost and time-scale needed to specify, create, and utilise synthetic environments for collective training, defence planning, and system acquisition. In order to achieve this goal, a number of objectives have to be met, and in particular, it is necessary to:
  - Determine and mitigate obstacles which prevent networked simulations from being exploited in Europe.
  - Provide a process and tools which will reduce the life-cycle of synthetic environment generation, execution, evaluation.
  - Set-up a European repository of simulation assets.

The experiences described in the previous paragraph aims therefore at providing the basic technical infrastructure, while the above projects will serve to provide basic, international common-ground to implement Operations and Methodologies areas.

CONCLUSIONS

Starting from four legacy simulators operating within the Simulator Department at Alenia Aeronautica, two of which have just undergone some substantial upgrades to their visual system, a seminal distributed simulation environment has been created. A shared geographical database is being developed for the new system, and once extended to all simulators a better visual correlation will have been achieved. A tactical scenario/CGF is part of the environment, with functions as both versatile visualisation tool and generation of semi-intelligent animated actors. This environment incorporates a stand-alone stereoscopic viewer that can be linked to the same synthetic environment, and an ACPT representing a Eurofighter "Typhoon", both stand-alone and fully integrated with the legacy simulators. The substrate for this environment is largely a dedicated TCP/IP Ethernet LAN, but plans for a reflective memory fibre-optic loop are under way. Interoperability with external entities is achieved through an HLA front-end, to be placed in the future reflective memory fibre-optic loop to represent the entire department as a single federate. Each simulator can also be easily identified as a federate by another suitable HLA front-end, without loss of performance. While this development is under way, Alenia is pursuing a company-wide initiative for the development of a Synthetic Environment aimed at supporting the aircraft design process. While basic technology experiences for SE infrastructures development are available, company processes and methodologies are under analysis through a number of of international collaborative projects.

LIST OF ACRONYMS

ACPT	Aircrew Cockpit Procedure Trainer
ALSP	Aggregate Level Simulation Protocol
CEPA	Common European Priority Area
CGF	Computer Generated Forces
DIS	Distributed Interactive Simulation
EUCLID	EUropean Co-operation for the Long term In Defence
FOV	Field Of View
HLA	High Level Architecture

IEEE	Institute of Electrical and Electronic Engineers
ISDN	Integrated Services Digital Network
LAN	Local Area Network
RTP	Research and Technology Project
SE	Synthetic Environment
SIMNET	Simulation Network
TCP/IP	Transmission Control Protocol/Internet Protocol
VME	Versatile Module Equipment
WAN	Wide Area Network
WEAG	Western European Armament Group

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Modelling Command and Control Teams

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Abstract

This paper describes a computational approach to modelling and simulating C2-team behaviour. Within this approach team models may be used to develop, test, and compare different C2-architectures, that is different structures and processes, without the need for real teams. The advantage of this method is to be able to identify the critical factors determining effective team functioning and to eliminate design inefficiencies at an early stage. Furthermore, different "what if" questions can be put to the test. The aim of the current approach is to develop and test credible *concepts* of how to organize C2-teams, not to produce complete one-on-one blueprints for future C2-teams.

The approach described below emphasizes the contingency relations between C2-structure and the characteristics of the mission and mission environment. Different environments require different C2-team behaviours: Therefore, flexibility, workload balancing, and team adaptation are important elements in our model.

C2-teams are complex because they consist of a large number of members and difficult interaction patterns. This means that we view team performance not only as an aggregation of the individual performances but also as the quality of interaction among the team members. In this approach the interaction between team members is modelled as activation spreading through a task network. For implementing the task network, we used the IPME modelling and simulation package.

The model also provides a workload-visualization tool that gives designers an overview of the functions that are being performed within the team. The overview of the workload distribution offers the designers insight in the team processes and possible bottlenecks. This insight can then be used to optimise the team architecture in an analyse-and-redesign loop. The overview is created by mapping the tasks and their workloads to a function taxonomy.

Introduction

The revolution in information technology that's taking place is changing the way decision makers within Command and Control (C2) teams interact and deal with conflicts within uncertain, dynamic and hostile environments. Therefore, the Royal Netherlands Navy (RNLN) recently (1998) launched a "future command" study aimed at reduced manning concepts and new organizational concepts for Combat Information Centres (CIC) of future frigates. The basic C2-functions to be fulfilled within a CIC are Situation Awareness (SA), Threat Assessment (TA), Decision Making (DM), and Direction and Control (DC). In the present situation of the M-frigate class, the planning and part of the monitoring functions are allocated to the warfare officers, whereas functions at the execution level are performed by operators of the different sensor and weapon systems (Passenier & Van Delft, 1997). Through technological developments in the area of automatic detection and sensor fusion it is expected that tasks at the execution level will become more and more automated, resulting in a workload shift from specific control activities to more general supervisory activities at the monitoring level. Additionally, apart from the increasing number of functions to be supervised,

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the total amount of available data in new C2-systems will increase. A second challenge to be met are the changing patterns of potential threats and conflicts in today's world requiring a strong defensive capability that is sufficiently versatile to execute a full range of operations, including different types of war and peace-keeping operations. Future increases for operational efficiency demands in terms of manning and training will become more and more important and forms a third challenge to be met. The three aspects mentioned—advanced information systems, organizational flexibility, and personnel requirements and training—must be tailored to support new C2-roles and requirements, to facilitate communication, operational planning, situational awareness, and dynamic distributed decision-making. In view of such demands on modern C2-teams, computer modelling and experimentation is put forth as a way to examine human decision-making and coordination processes and to identify organizational team-structures that lead to superior performance.

In order to be able to experiment with different team structures we opted for a computer model approach that simulates the performance of realistic C2-teams. The advantage of such an approach is that it provides a platform which we can use to think through, elaborate upon, and experiment with C2-team designs without the need of first creating such teams in the empirical sense. This is analogous to, for instance, the way vessels and ship bridges nowadays are being designed and tested in virtual work environments (e.g., Punte & Post, 2001). These virtual approaches give designers and stakeholders an early sense of the operation ability, the ergonomics, and the look and feel of a design. The advantage of these design tools is that they allow the designers to think about the model, to experiment with it, and in doing so, to eliminate design mistakes not noticed in earlier 2D representations. Optimisation of the design concept before a ship is actually built is very cost efficient, and is in that sense an improvement of total-quality management. A second rationale for computer modelling is that, although inference from empirical data is an important element in gaining scientific knowledge (e.g. Essens, Post, & Rasker, 2000), the large cost associated with experimentation, however, makes it impractical to rely on empirical experimentation only. This is especially true when dealing with organizational behaviour of human teams designed to operate in a complex multitask mission environment. Furthermore, experimenting with experienced team members in different roles and hierarchical relations has the potential for biases because these experts are trained and have gained operational experience and knowledge, which they cannot ignore at will. A computer modelling and simulation approach circumvents these impracticalities and provides a tool which makes experimentation with different C2-team designs possible and has the conceptual potential of contributing to developing and empirically validating theories and models of human decision-making in distributed systems. The ultimate goals for us, and indeed for the scientific community as a whole, would be to develop models, insights, and knowledge, which could ultimately contribute to design modifications that enhance team-level performance.

For our research into future C2-team design, we used the Integrated Performance Modelling Environment (IPME) to model and simulate C2-team behaviour. IPME is based on Micro Saint and HOS and is a network simulation package for building models that simulate human and system performance. The IPME models consists of a workspace design that represents the operator's work environment, a network simulation, which is a Micro Saint task network, and micro models. These micro models (which come from HOS) calculate times for various activities such as walking, speaking, and pushing buttons. They provide an interface between the network and the workspace (i.e. the environment), and they offer a much finer level of modelling resolution than is typically found in most Micro Saint networks. The integrated performance package runs on UNIX platforms. Furthermore, it contains tools for determining workload and effects of environmental and mission circumstances on operators.

The current modelling and simulation approach is intended to enable the comparison of different team designs and to find out how team structures perform under different mission conditions. Thus, comparing different team designs requires: a) devising different organizational structures, b) the development of a set of measures to characterize various dimensions of organizational performance, and c) the creation of different sets of mission condition, called scenarios. We defined three team organizations that differ in the way they adapt to changes in the environment. Comparing different team designs consequently means measuring performance on the team level. Some of the performance indicators we used are: balance of workload distribution, the promptness of responses, communication and coordination load, and the response quality, to name a few. We view *team*

performance an *emergent* property not only of the individual performances but also of the quality of interaction among the team members (Van den Broek, 2001). In line with Simon (1969), we view teams as “complex systems [because they] are made-up of a large number of [members] that interact in a non-simple way. In such complex systems, the whole is more than the sum of the [members] in the important pragmatic sense that, given the properties of the [members] and the laws of their interaction, it is not a trivial matter to infer the properties of the whole” (cited in Van den Broek, 2001: p. 4).

The detailed C2-team models (unit-level models) that we are building are referred to as *emulation models*. Pew & Mavor (1998) describe emulation models as follows: “Emulation models are large models intended to emulate a particular organization [or team] in order to identify specific features and limitations of that unit’s structure. Such models enable the user to make specific predictions about a particular organization or technology. Emulation models are difficult and time-consuming to build; however, they provide policy predictions, through typically only on a case-by-case basis. These models typically have an extremely large number of parameters or rules and may require vast quantities of input data so they can be adapted to fit many different cases. To run the emulation, the user often needs to specify these parameters or rules, using data on the particular organizational unit being studied. The model is then adapted to fit the past behaviour of this unit. Once this adoption has been done, the model can be used to explore different aspects of the organization being studies and to engage in “what if” analysis. One of the main uses of emulation models is getting humans to think about their unit and to recognize what data they have and have not been collected. These models are particularly useful for engineering the design of a specific unit (p.: 275)”. This description fits our approach exactly. However, we will stick to using the *modelling and simulation* label to avoid misconceptions.

With the IPME modelling approach we aim to a) demonstrate the methodological possibility of simulating C2-team behaviour based on a task network approach used to model human performance and b) to show that such an approach can produce valuable and tested knowledge concerning the relation between team structural properties and mission characteristics. Hence, the method and practice described below is not intended to produce an exact blueprint for future C2-team structure and its operations, nor is it a method for determining the “best” team size. What our approach produces, however, are credible design principles based on the relation between size, mission characteristics, and performance. In other words, the simulation models provide (computationally) validated answers to specific “what if” questions. For instance, what is gained and what is lost when the team is downsized to a certain extent, which missions are still possible and which aren’t, which conditions can still be met, etc.

The structure of this paper is as follows. First, we provide some background concerning the organizational design problem in relation to mission characteristics. After that, we introduce IPME as a modelling and simulation tool and discuss its basic assumptions. In the last part of this paper we explain the experimental design of the current modelling effort and explain the relation between IPME performance measurement and team-level performance measurements in detail.

Organizational Design Problem

As the functioning in the CIC is accomplished by a team of operators and decision-makers, we speak of “team design” when we discuss principles on the basis of which future teams may be designed. Team design deals with the various ways in which teams can be designed, taking into account numerous factors moderating or mediating the resulting team performance. The area of team design is not as well defined in the literature as the area of organizational design. Szilagyi & Wallace, (1990) define organizational design as “…the process of achieving a coordinated effort through the structuring of tasks, authority, and work flow” (p. 618). The same definition could be applied to the area of team design, with teams being a lower level in the organization as a whole. In fact, Paley, Levchuk, Serfaty, & MacMillan (1999), described the team design process as an algorithm-based allocation of mission tasks, system resources (e.g., information, raw materials, or equipment), and the human decision-makers who constitutes the team. The result of the team design effort is a team structure that specifies both the structure and the strategy of the team, including who owns resources, who takes actions, who uses information, who coordinates with whom, the tasks to

be coordinated, who communicates with whom, who is responsible for what, and who shall provide backup to whom.

The problem scope and complexity faced by large-scale C2-systems that involve humans, machines, workstations, networks, and databases interacting within an organization require that the decision-making and operational functions be distributed over several team members, of which picture 1 provides an impression.

Picture 1: A CIC impression

According to Levchuk, Pattipati, & Kleinman (1999), the geographically separated decision-makers must coordinate their *information*, *resources*, and *activities* in order to achieve their common goal in what is generally a complex, dynamic, and uncertain mission environment. Since the decision-making and operational capabilities of a human are limited, the distribution of information, resources, and activities must be in line with the decision-making and operational load of each decision-maker and must remain below corresponding workload thresholds. Due to decentralization in large-scale systems, each decision-maker has access only to a portion of the information available to the team. Moreover, in realistic situations the total information set may be incomplete and inaccurate due to lax updating, missed detection of events, and errors in data collection. The critical issues in team *information processing* are: who should know what, who should communicate what and to whom, and when people should and should not communicate. The total decision-making and operational load is generally partitioned among the decision-makers by decomposing a mission into tasks and assigning these tasks to individuals who are responsible for their planning and execution. Moreover, an overlap in task processing gives the team a degree of freedom to adapt to uneven demand by redistributing workload. The critical issues in *team task processing* are: what should be done, who should do what, and when. In general, decision-makers are provided with limited resources with which to accomplish their objectives either in information processing or in task processing. The distribution of these resources among the decision-makers and the assignment of these resources to seek information and to process tasks are key elements in an organization's design. The critical issues in *team resource allocation* are: who should own or transfer a specific resource, when, and for how long.

C2-teams as a task network

While the functions that are carried out by a C2-team may vary based on the makeup of a specific mission, the general classification of the basic processes inherent to C2-teams is critical to the evaluation of the organizational design process. The facilitation of the fundamental processes common to a large variety of C2-teams (such as coordination, communication, management of weapons, operational planning, situation awareness, dynamic distributed decision-making, etc.) is

the key to superior team performance. The optimal design of adaptive C2-teams is a design that maintains a proper balance among the following general intrinsic processes:

- Segmented information acquisition and processing
- Distributed decision-making
- Coordination
- Mission monitoring / Situation awareness
- Failure and anomaly detection
- Strategy adaptation / reconfiguration enforcement
- Workload balancing
- The challenge to C2-team design is device a structure that maintains a proper balance among these processes and at the same time maintains certain performance criteria, such as the quality of response (making the right decisions), and the response speed (promptness of reaction).

Collaboration processes quality

Until now, we discussed a C2-team as a complex distributed decision-making system for which we seek an optimal design in balancing basic processes through adjustments to the team structure. However, the quality of interpersonal relationships between the team members is also seen as a major determent for team performance and the collaboration process.

A C2-team as a whole has certain features like team maturity (how long have the team members been together as a team), team diversity (how homogeneous is the team in terms of experience, gender, age, background), and team cohesion that may influence the quality of the collaboration processes to some extent. Other, interpersonal elements within a team, such as leadership, assertiveness, supportive behaviour, communication quality, motivation, etc. are considered influential the quality of the collaboration process. However, we lack empirically validated models that identify the basic interpersonal concepts, the composite concepts, and the aggregated concepts and their causal relations. For instance, are team cohesion and social support concepts on the same abstraction level or is team cohesion an emergent property, which grows when there is strong social support and vice versa.

Besides conceptual and causal difficulties, it is not clear how these concepts should fit in the organizational structure and processes. We all recognize that social support and motivation are beneficial for the collaboration process, but when modelling the boosting effect of team member motivation, one has to translate it into effects on processes. For instance, motivation increases the chance that team members will correct one another’s mistakes.

Because of these conceptual uncertainties and because of the exponential growth of the number of parameters that can be varied experimentally, the interpersonal aspects of the collaboration process are omitted from the current model and from this discussion. This is not to say that we deem the issue to be unimportant. Indeed, within our department we are working on establishing empirically validated models, which in due time will be integrated within the team models. The results of those studies will be reported in the near future.

IPME provides ample possibilities for integrating team and individual parameters that influence the task performance (both time and quality) and collaboration process. For instance, each team member is viewed as a single simulation object and has default and user definable physical and psychological characteristics. Each simulated team member (operator) has a set of characteristics that consist of *properties*, *traits*, *states*, and *anthropometry*. These, characteristics have attributes (e.g. fatigue, which is an attribute of state), which have values (e.g. high, low) and which may influence task performance. For instance, it is possible to model that when fatigue is high for a certain operator (influenced by the simulation time) the probability of task failure increases with, for example, 10%.

Modelling Missions

Research on organizational performance has demonstrated that a strong relationship exists between the specific structure of a task environment (e.g. the mission) and the connected organizational design. Subsequently, the optimalisation of an organization design depends on the actual mission parameters (and organizational constraints)—i.e. there is no universally "best" organization (Galbraith, 1973). Furthermore, according the contingency theory there is a relation between the characteristics of the environment and the type of organization that is required. In general, a complex environment requires a complex structure while a more simple and predictable environment requires a simple or simpler team structure. From this it follows that an organization operates best when its command and control architecture—its organizational structure and processes—fits, or matches, the characteristics of the mission task environment. Consequently, it can be concluded that the optimalisation of an organizational design ultimately depends on the actual mission structure and its characteristics.

The sine qua non duality in modelling a mission and an organization can be observed by recognizing that it is impossible to classify all decision-making activities without knowledge of the type of mission that the organization will be facing. In turn, to decompose a mission into tasks requires the knowledge of resources available to the organization. Hence, it is important that the modelling of both the mission and organization is carried out simultaneously to elucidate the functional reciprocity between the two structures.

The modelling of both the mission and C2-team organization has been carried out in a previous study in order to classify the activities involved within combined AAW, ASW, and AsuW missions (Essens et al., 2000). This study resulted in what we called a descriptive model and forms the basis for the dynamic IPME modelling effort. The descriptive model identifies the different operators and decision-makers that are part of the C2-team, the basic mission tasks, and how team members are related to tasks in relation to the events taking place. For instance, air contacts that are on pre-described airways are handled and identified on a lower hierarchical level than air contacts that are outside pre-described airways. The tasks the descriptive model identifies are assumed to be constant even when the C2-team structure or task assignment changes. This is because the type of mission the C2-team will be facing determines the actions required. In other words, basic mission activities like detection, tracking, and identification remain essential activities even when the team structure changes. Hence, team structure, task assignment, and hierarchy are variable within the models; the mission tasks are not.

Another element of modelling missions is the set of events that occur within a mission, which set is referred to as a *scenario*. Scenario events are outside occurrences that somehow trigger C2-team activities. Mission events could be the detection of physical objects like air contacts and surface contacts but could also be information from external sources like coastal stations and observation plains. Physical objects, like air contacts, have behaviour in time based on attributes like speed, altitude, direction etc. The attribute values can and do change over time. Changes in behaviour are to be viewed as events because the significance of these changes has to be established in terms of immediate or emergent threat assessment. For example, detecting that an air contact leaves an airway triggers an action pattern. Hence, events are not simply physical objects but include behaviour and (significant) changes in behaviour; the constant monitoring of these behaviours causes much of the workload. Within IPME, it is possible to define 'outside' objects and their behaviour as a series of events.

Modelling Paradigm

IPME modelling rests on the assumption that human behaviour can be modelled as a set of interrelated tasks. That is, an IPME model has at its heart a task network, see figure 1. The task network model allows a user to describe the processes used by a human operator to perform an activity. It also addresses the design parameters of the workspace in which the processes must be performed and the use of those design parameters to calculate times and accuracies of the processes in the activity. Completion time and accuracy of the tasks are modelled stochastically using probability distributions whose parameters are selected by the user. It is assumed that the operator workload imposed by individual tasks can be aggregated to arrive at composite workload measures.

Further assumptions are that system behaviour can be modelled as a task (or function) network and that the (mission) environment can be modelled as a sequence of external events.

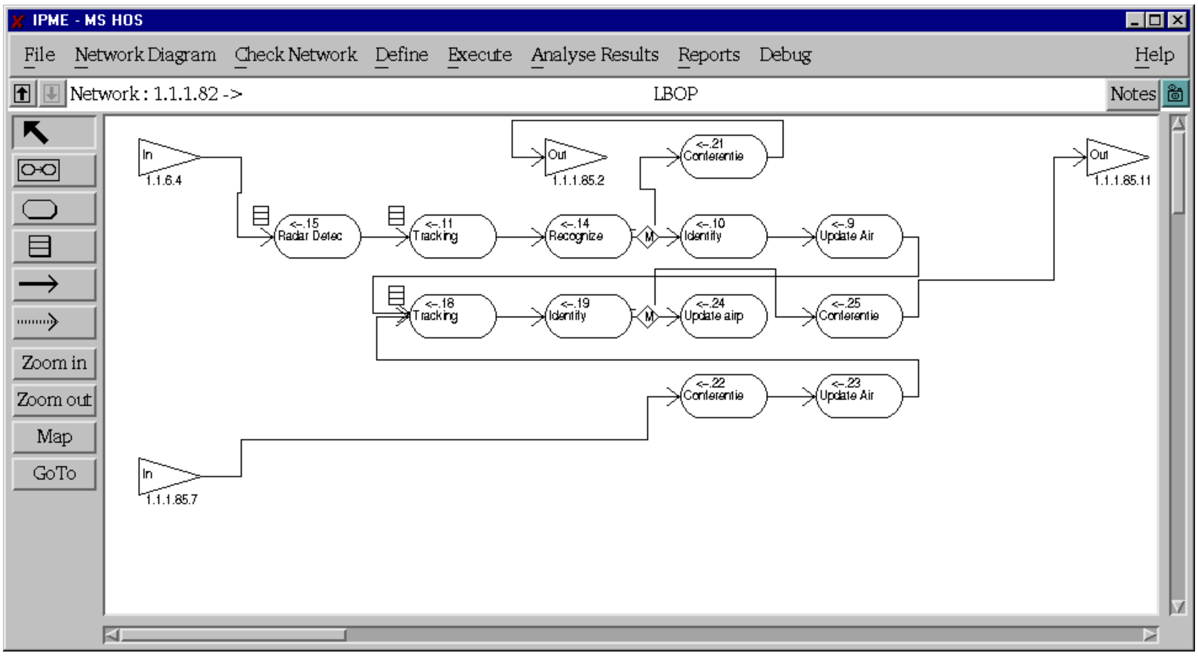

Figure 1: A task network example

IPME is an integrated modelling environment that, besides a task network of processes and procedures, consists of an environment model, a crew model, a performance-shaping factor model, and optional external models. These component models are configured into a composite “system” model. The integration of these models creates a unique environment for human system modelling. Once models are created, they can easily be added to or removed from a system model.

IPME can run in three different modes: IPME mode, POP mode, and IP/PCT mode. The POP and IPME modes address workload with different algorithms. The IPME and POP modes use a model based on performance-shaping factors and a taxonomy mapping between performance-shaping functions and individual tasks. The IP/PCT mode uses the Information/Perceptual Control Theory Model.

Task network

The nodes of a task network are tasks. Human operator tasks fall into the following categories: visual, numerical, cognitive, fine motor (both discrete and continuous), gross motor, and communications (reading, writing, and speaking). The arcs of the network are task relationships, which are primary relationships of sequence. Information is exchanged among tasks by means of shared variables. Each task has a set of task characteristics and a name as an identifier. The user must specify the type of probability distribution used to model the task’s duration and provide parameters for that distribution. A task’s release condition is the condition(s) that must be met before the task can start. Each task can have some effect on the overall system once its starts; this is called its beginning effect. Its ending effect is how the system will change as a result of task completion. Task logic branching defines the decision which path to take (i.e., which task to initiate) once a task has been completed. For this purpose, the user must specify the decision logic in a C-like programming language. This logic can be probabilistic (branching is randomised, which is useful for modelling error), tactical (a branch goes to the task with the highest calculated value), or multiple (several subsequent tasks are initiated simultaneously). Task duration and accuracy can be altered further by means of performance-shaping functions used to model the effects of various factors on task performance. These factors include personnel characteristics, level of training, and environmental stressors (sea state, background noise, etc.).

The outputs of a IPME model include mission performance data (task times and accuracies) and workload data. Because IPME models have historically been used in constructive (as opposed to virtual), they execute in fast time (as opposed to real time). Internal and external initial events are

scheduled; as events are processed, tasks are initiated, beginning effects are computed, accuracy data are computed, workloads are computed, and task termination events are scheduled. As task termination events are processed, the system is updated to reflect task completions.

IPME is not so much a model of human behaviour, let alone of team behaviour, as a modelling language and a collection of simulation tools that can be used to create human and team behaviour models to meet users' needs. Hence, different ways of (theory-based) team behaviour can be implemented within the IPME package. Consequently, each implemented model must be validated on its own by adapting the model to fit the past behaviour of the team it is simulating. Once this adaptation has been successful completed, the model can be used to explore different aspects of the organization being studied and to engage in "what if" analyses.

Experimental design

Figure 2, depicts the experimental design of the current M-frigate project. The experimental design contains three modelling elements that may be varied experimentally. The independent variables are (1) mission scenarios and structure and (2) number of team members. The dependent variable is (3) performance.

Mission scenarios

The study covers combined Anti Air Warfare (AAW) and Anti Surface Warfare (AsuW) missions. Within these types of missions, a large number of different scenario's can be designed as input to the C2-system. As stated above, there is a sine qua non duality between environmental characteristics and the team structure. In order to test C2-team performance under various mission conditions we identified three dimensions for characterizing different mission scenarios. According to these dimensions, mission scenarios can be classified as those that contain *time critical elements*, those that emphasize *volume*, and those that contain *uncertainty* elements. Time critical scenarios are scenarios that contain both air and surface events that require a prompt and accurate defensive reaction, for instance a missile attack or an attack with a fast control boat. Responses to these types of attacks follow specific and well-trained procedures in which every decision-maker knows what to do and what not to do. Volume scenarios are scenarios in which the sheer number of both air and surface contacts cause both high information and operational levels resulting in high workload levels of mission tasks and, therefore, may cause workload imbalances within the C2-team.

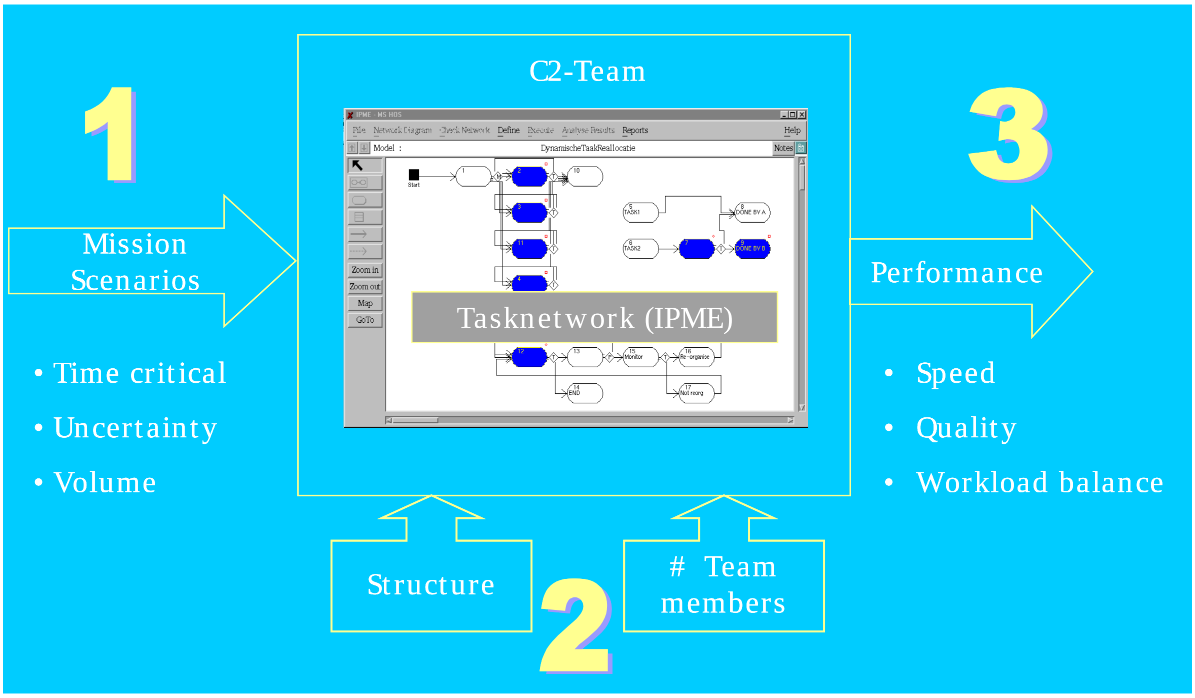

Figure 2: Experimental design

Uncertainty, within mission scenarios has to do with not knowing the intention of detected contacts. This requires for instance that these contacts have to be monitored constantly and that substantial effort must be put in, requiring additional intelligence and information. Uncertainty can also refer to whether or not two or more contacts form a tactical unit in the sense they may or may not cooperate in outmanoeuvring the frigate. Additional composite scenarios are also possible, which we characterize as *complex* mission scenarios.

The different mission scenarios, which determine the operational, communicational, and coordination demands, may be seen as the input variance of the C2-team model.

Structure and the number of team members

The experimental variations of the C2-team design concern the structure and the number of constituent team members. An organizational structure prescribes the relationships among the C2-team members by specifying:

- The resource access and allocation of the team members
- The command hierarchy
- Inter-communication network

Thus, a specific organizational structure defines each team member's *capability* (by assigning each team member a share of the information and resources) and specifies the rules that regulate *coordination* among the team members. The organizational structure together with a set of thresholds constraining the team member workload, determine the boundaries of a feasible strategy space (e.g., all feasible task-resource assignments among the team members), from which the organization can choose a particular strategy. The feasible strategy space delimits the strategy adjustments that an organization can undertake without structural reconfiguration. Hence, an organizational strategy defines a feasible mapping between an organizational structure and a mission structure, assigning each team member a share of the activities while specifying the resources to complete a particular mission task. A specific organizational strategy delineates the timetable for the mission and specifies resource utilization and individual team member workload by prescribing:

- Task-resource assignments among the team members
- Task processing schedule

Based upon the structural ingredients described above, different C2-team structures (e.g., different command hierarchies, different allocation of team members, different lines of communication, etc.) can be designed. For the current M-frigate study, we defined three different structures to compare:

- A general hierarchical
- A structure in which duo's (e.g. small sub-teams), collaborate intensively
- A non-hierarchical structure

The hierarchical structure is pretty much a model of the current C2-team practice. We explicitly choose to model the current state of affairs because we wanted to produce a basic model for determining the baseline performance, which than can be used for comparing the performance of the other C2-structures. The second incentive was that we wanted to test the predictive power of the model by validating the performance outcome with data of empirical workload studies we conducted in the recent past (Essens, 2000). The idea of creating small sub-teams came from observations of current C2-practice. The idea behind it is that team members who have strong and frequent task interdependencies should be co-located. Co-location makes face-to-face communication possible which is beneficial to the cooperating and coordination process because the communication takes less time and is more direct. In addition, non-verbal communication and direct observation enriches the cooperation process. Modelling a non-hierarchical structure is a way to estimate what is gained and what is lost when, in a radical way, the concept of hierarchy is abandoned altogether and work with generically trained decision makers who can and may fulfil all

possible mission tasks. We do not perceive the non-hierarchical structure as a model for the future per se, but as a model to come to grips with a number of very basic concepts.

Performance

The third element of the experimental design is performance measurement. Each C2-team structure has a relative performance in relation to the different mission scenarios, that is how well does a certain C2-team structure perform under certain mission conditions. In addition, we stated that an organizational strategy defines a feasible mapping between an organizational structure and a mission structure. The question then is: What are the boundaries of the mission structure that prevent the organizational structure from producing a feasible strategy? In other words, what kind of missions, in terms of pressure and uncertainty, the team is able to handle? We stated above that different mission structures might need different C2-team structures. Therefore, it is likely that there is no “best” structure to cover all situations; instead what is needed is flexibility of strategy and/or structural reconfiguration capabilities within the model.

Performance evaluation

Performance evaluation provides information for improving a team design, or, when it concerns a comparative evaluation, for selecting the best team design. Performance can be measured according to a number of criteria, such as speed, quality, and workload distribution, but for the moment we will focus on workload distribution only.

Ideally, one would like to understand how workload is distributed over time and over all members of the C2-team. This provides insight in how well the workload is balanced over time, or whether some members have to do too much at one particular moment, leading to errors or delays, while others do not carry their weight. This workload distribution view should be ideally expressed as a summation of the work that is carried out during certain time periods by all individuals. In the same view, one would like to know the maximum individual and teamwork load capacities, in order to know for a particular team design if the performance borders have been reached or if there is room still for improvement. Figure 3 provides such a team work load distribution view.

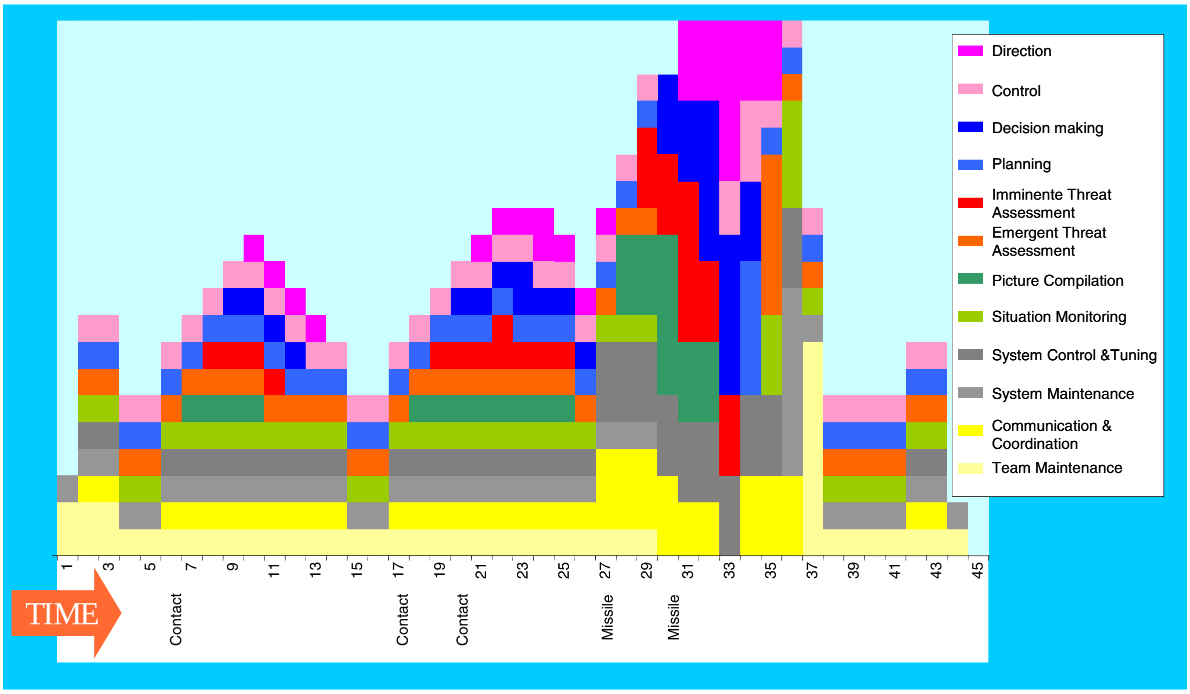

Figure 3: Workload distribution on the team level

To clearly distinguish the four basic C2-functions previously mentioned—Situation Awareness, Threat Assessment, Planning & Decision Making, and Direction & Control—the associated workloads are visualized with different colours. We have added two other main tasks, namely

System Tasks and *Team Tasks*[1]. We further decomposed each main function into two components: a continuous part, and an event-driven part. The continuous (event independent) part exists of work that enables an immediate reaction to an event, and encompasses the preparation of the different functions involved. This means that preparation involves things like planning, remaining in the loop, system maintenance, the assignment of tasks and responsibilities, etc. The event-driven part is work that deals (directly) with events (e.g., processing a contact, taking a decision, deploying a weapon). Continuous work is presented with light colours, and the event-driven work with dark colours. The functions are listed in table 1.

Table 1: Main functions

Main Functions	Function Name	Type	Explication
Direction & Control	Direction	Event-driven	Ordering
	Control	Continuous	Monitoring execution
Planning & Decision-Making	Decision Making	Event-driven	Including decision taking
	Planning	Continuous	Anticipation, Preparation
Threat Assessment	Imminent Assessment	Event-driven	Reaction needed
	Emergent Assessment	Continuous	Reflection needed
Situation Awareness	Picture Compilation	Event-driven	Establish picture
	Situation Monitoring	Continuous	Watch
System Tasks	Control & Tuning	Event-driven	Adjust specific settings
	System Maintenance	Continuous	E.g., clean desk
Team Tasks	Comms & coordination	Event-driven	Also information exchange
	Team Maintenance	Continuous	Evaluation, briefing, etc.

Figure 3, represents a C2-team carrying out continuous work for each main function, and each event will cause a gulf of additional work which stretches the team workload capacity to its limits. The volume of work is expressed by the workload and the processing time for each function. The x-axis represents the mission duration (time). The y-axis represents the workload and how the workload is distributed over the functions. In the example, processing a regular contact, for example, takes twice as much time as for instance a missile attack. The workload, however, of a routine mission is only half as much compared with a missile attack, which requires all the available resources and perhaps even more. Hence, the graph shows the total workload and function distribution in relation to the events taking place during the mission. The picture also produces information on which functions are being fulfilled at various moments in time and which are not though possibly should be done. This kind of information is valuable because it reveals whether or not the team is still functioning as a team. For instance, in times when tension builds and workload increases accordingly, team members tend to focus on the mission tasks for which they are responsible and consequently tend to neglect team tasks, such as information exchange and coordination. The consequences of this neglect may be that in times of high-pressure team coordination declines causing a decline in execution efficiency and robustness, which could potentially add to workload stress, causing a negative spiral of efficacy loss.

The workload distribution shown in figure 3 can also be generated for each individual team member. In fact the overall workload distribution is a summation of the workload distributions of all the team members.

[1] We could have included their workloads in the other main functions but then we would have lost insight into these particular functions of interest.

From individual performance to team-level performance

Within IPME, performance measures are obtained from the individual task level, which are the following:

- Time on task
- Task failure
- Task interrupted
- Tasks delayed
- Tasks shedded (not carried out)
- Workload
- Situation awareness
- Task priority transformation

These task performance indicators will be used to establish the team-level performance. Especially workload will be used to express the workload distribution within the team. In order to aggregate from the task level to the team level we established a link between the model and an Excel program. Within the Excel program the workload data per team member and per task are aggregated to the team level workload distribution. This was done by clustering and mapping the workload levels of individual tasks onto the function taxonomy. This procedure is depicted in figure 4.

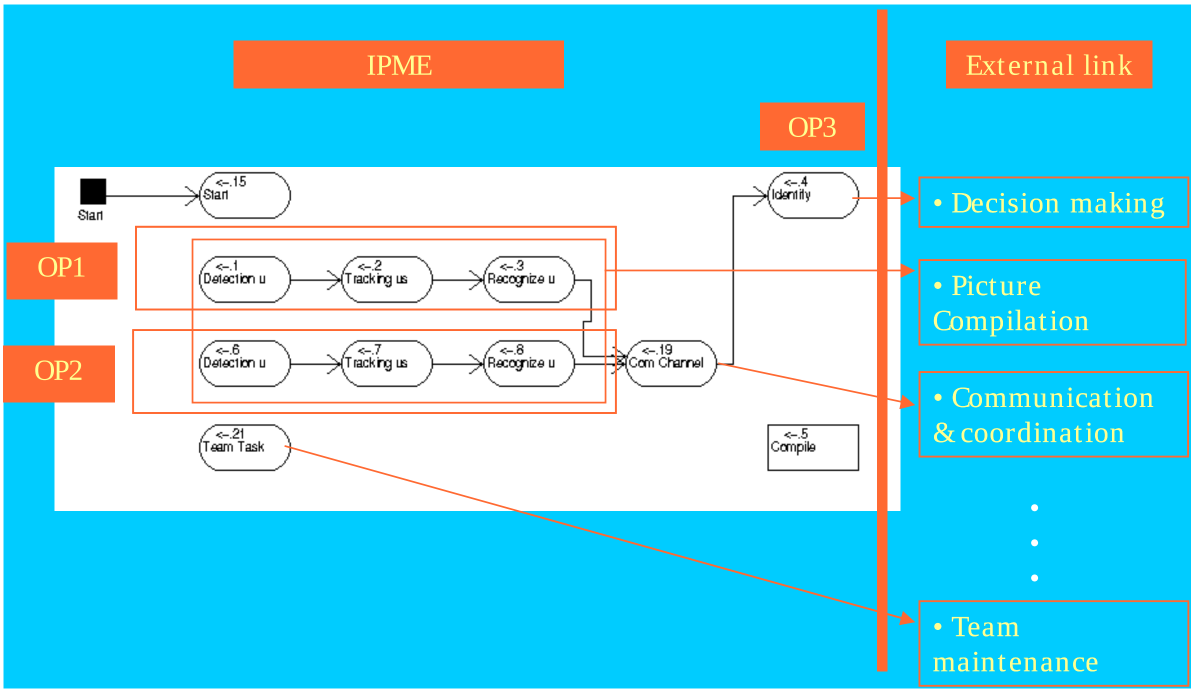

Figure 4: Mapping individual tasks to the function taxonomy

The picture shows that task labelled “detection,” “tracking,” and “recognize” is to be mapped to the function category “picture compilation.” The picture also shows that the clustering can be done by team member (operator) or across operators.

In summary, we can say that the workload of the individual team members depends on the activation distribution within the task network. The activation distribution depends on many design parameters, structural properties, and team member characteristics. The team level performance overview, figure 3, depicts on the aggregation level how the activation spreading translates to functions performed, functions not performed or postponed. Hence, the work distribution graph is intended to be an interpretative tool. Changes, however, that designers may want to bring about on the team level, must be implemented and realized on the task-network level in terms of its parameters, structure, and member characteristics.

Work in progress

The method and work described in this paper is very much work in progress. This means that we cannot produce comparative data yet. Instead we are putting all of our effort in to building the basic model and establishing the link between IPME and the visualization tool that produces the team-level workload distribution overview. We also are investigating the possibility of linking IPME to a scenario generator tool.

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Abstract

In this paper the objectives and goals of the US national portion of the joint German (GE) and US Simulation and C2 Information Systems Connectivity Experiments (SINCE) program will be described. In SINCE the US is using Modeling and Simulation (M&S) technologies as an essential part of our C2 systems and supporting capabilities research and development (R&D) process. In the US SINCE program M&S is being used to change the way the US Army defines, designs, develops, integrates, tests and evaluates new concepts, technologies and equipments for the future battlefield. M&S provides a cost-efficient means for evaluating the application of new/evolving C2 system technologies and associated operational concepts with military users in a more flexible and cost effective environment than traditional live hardware/software demonstrations. By enabling the technical and operational user communities to actively participate in the development, application and evaluation of new technologies/concepts for implementation of future C2 systems, M&S is helping accelerate the transition of these new products and systems capabilities into full-scale development programs. The U.S. Army team of technical and military subject matter experts supporting the SINCE program are composed of participants from the US Army Communication Electronics Command (CECOM), Command and Control Directorate (C2D), Fort Monmouth NJ, and the US Army TRADOC Mounted Maneuver Battle Laboratory (MMBL), Ft Knox KY and Battle Command Battle Laboratory (BCBL), Ft Leavenworth KS, and the US Multilateral Interoperability Program (MIP) and Simulation to C4I Interoperability (SIMCI) activities. This paper will describe the establishment and implementation of US simulation/stimulation capabilities for brigade and below C2 systems and associated M&S interoperability support activities being conducted to meet the requirements for planned SINCE Phases 1, 2, 3, and 4 experimentation efforts. Virtual simulation capabilities that include the integration of live hardware/software systems will be implemented to support SINCE experimentation activities. Constructive, or "war game" simulations will be used to determine the joint combat effectiveness of Command and Control Information System (C2IS) technology and "fill out" the battlefield during virtual-live experiments. This paper will describe how the US expects to use these tools as part of the overall C2IS engineering development process. This paper will also discuss how these SINCE experiments will be leveraging High-Level Architecture (HLA) concepts and solutions to evolve towards a collaborative C2 information systems engineering and interoperability experimentation support environment. In addition to describing US national SINCE program approach and technical implementation strategies, this paper will also address and describe the international aspects of the joint SINCE program with the Federal Republic of Germany. One of the key objectives of the joint US/GE SINCE program is to define, implement, experiment, and demonstrate generic solutions for interfacing, networking and using emerging Brigade (BDE) and Battalion (BN) Modeling and Simulation (M&S) support capabilities and appropriate C2IS in support of future international C2 experimentation activities.

Introduction

The major thrust of the US SINCE program is focused on providing future Army Transformation, 2010 Objective Force and Future Combat System (FCS) Commanders with enhanced capabilities to conduct and coordinate collaborative military mission planning, execution monitoring, re-planning and mission

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management activities in support of combined Army and joint coalition force operations. Essential goals for the US effort are demonstrating improved means for visualizing the coalition battle space and providing the capability to perform real-time collaboration and information exchange with coalition partners during the conduct of mobile operations. During the conduct of US/GE SINCE experimentation activities the US expects to harmonize evolving US Army Mission Planning, Execution Monitoring and Battle Management Decision Support Tools so that they can better support coalition operations. The US also expects to demonstrate new, more affordable means for achieving interoperability between US Objective Force/FCS C2IS and those of our coalition partners. In the execution of SINCE, the US will integrate and use M&S technologies to facilitate/support the planning, re-planning, execution monitoring and management of complex joint and combined coalition missions/operations.

US Army Transformation Process

As you can see from Figure 1 below, the US Army is on a rapid path to transform itself into the envisioned Objective Force. This transformation processes leverages many different emerging technologies to both improve and radically change the way the US Army will execute future military operations. However, while the US Army's transformation to the Objective Force will introduce many new C2 and Weapon Systems capabilities into the Battle Space, these new systems will still have to interact with and really support many legacy systems currently being placed into the battlefield.

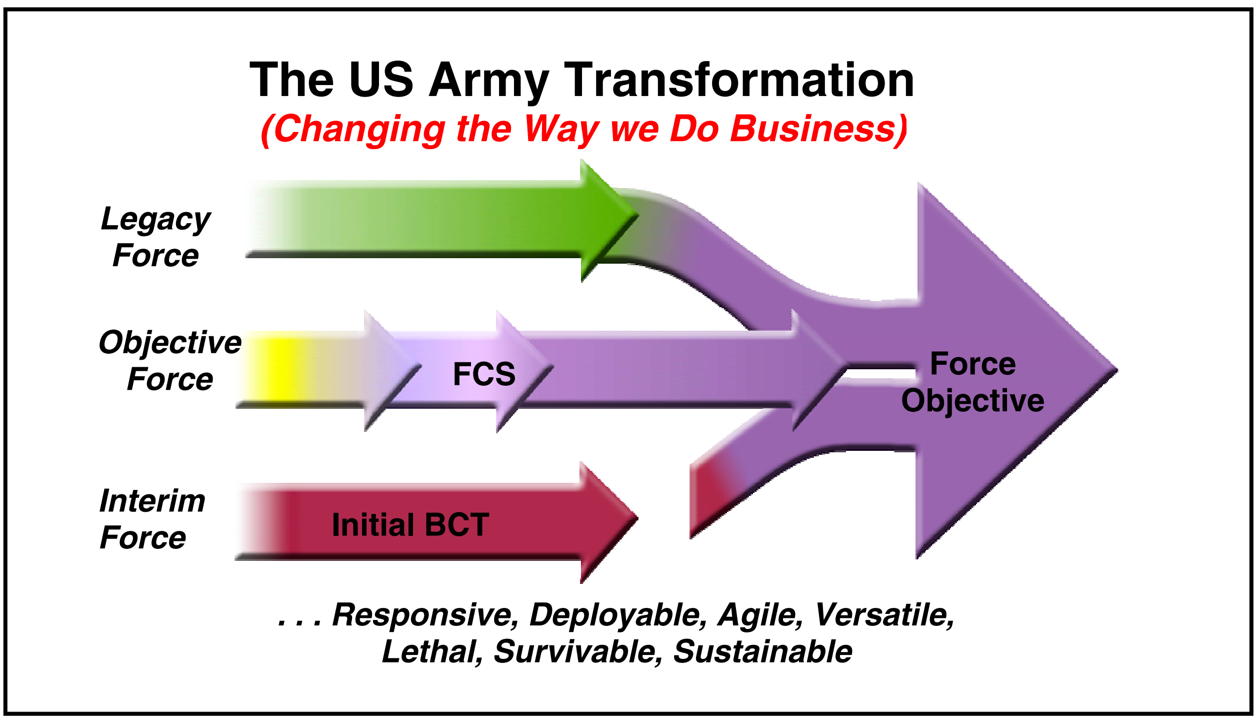

Figure 1: US Army Transformation to the Objective Force

Several core C2 enabling technologies/capabilities have been identified as critical to the success of this transformation process. They are implementation of real-time Situation Awareness and Battlefield Visualization, the ability to perform rapid Course of Action (COA) development, planning, rehearsal, analysis and execution monitoring, the capability to perform collaborative C2 On-the-Move, and support of joint/coalition information exchange interoperability.

SINCE Program Focus

The focus of the SINCE program is directed at the tactical 2010 Brigade, Battalion and below coalition force operational environment. While the actual force structure and operational concepts for the 2010 Objective Force and FCS are still in development phase, it is clear that these forces still will have to perform many of the same C2 planning and mission management functions/tasks that their traditional counterparts do. The new challenges for the Objective Force/ FCS commander is that these functions/tasks will have to be performed faster, while on the move and in a more collaborate manner, both internally with US forces and with our coalition partners. Significant emphasis on Objective Force/FCS leadership training will focus on fighting the evolving mission/situation rather than executing the plan. The US/GE SINCE program activities will address both traditional war fighting and Stability and Support Operations (SASO) coalition force missions. In the execution of our SINCE program activities, the U.S. will emulate as best as possible, the evolving Objective Force C2 Information Systems (C2IS) Tactics, Techniques and Procedures (TTP), operational doctrine, technical system concepts and architecture, etc. We will use this mechanism to experiment with and improve the way the US can perform collaborative mission planning, mission execution monitoring and management in support of a coalition force operation. The focus issues of SINCE experiments are not on implementing information exchange interoperability, but rather on developing and validating of common situation awareness, mission and operation execution understanding once the information has been exchanged. Interoperability is a starting requirement and the starting assumption for these experiments. Both the US and GE expect to use and implement information exchange interoperability solutions that other international fora have already developed and determined to meet current coalition force Information Exchange Requirement (IER) needs.

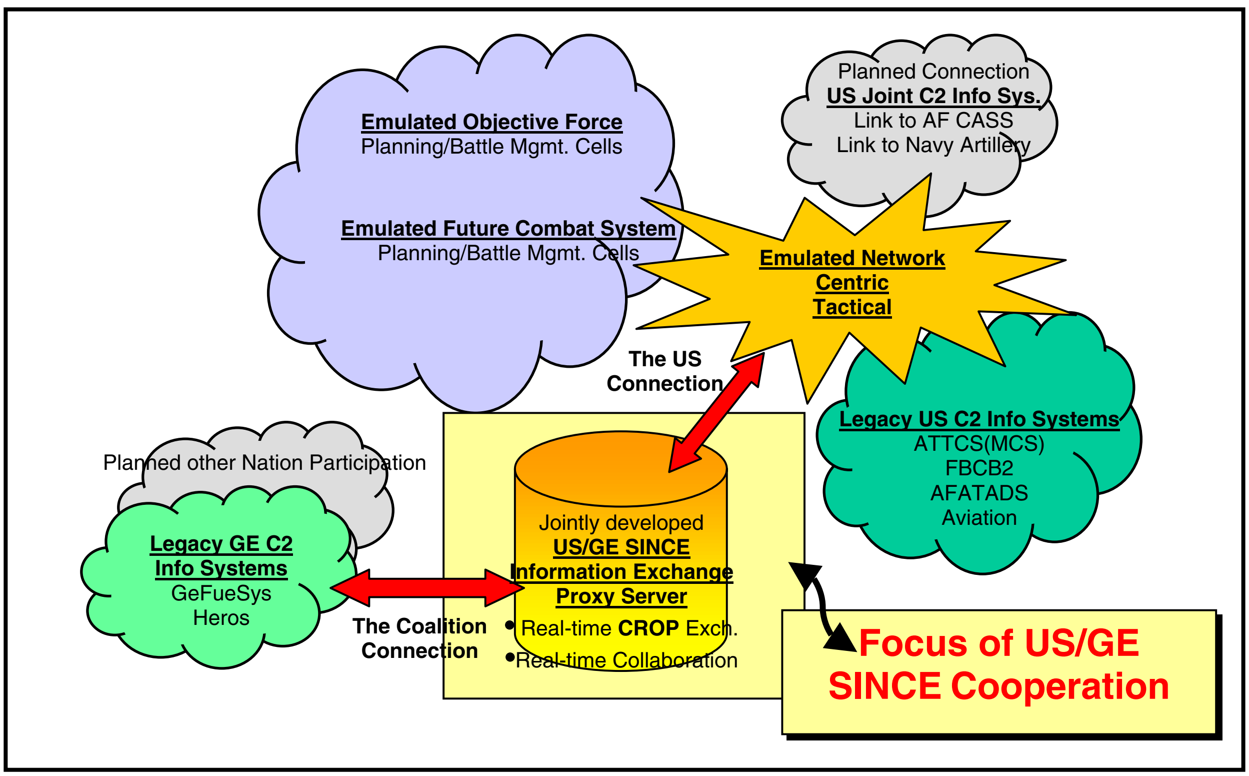

Figure 2: US Internal and Joint SINCE Effort (Focused on How we will Operate in the Future)

Instead, SINCE will implement and concentrate on understanding the real-time coalition Common Relative Operating Picture (CROP) developed from these information exchanges, and how to use this understanding to support the coalition force mission planning, execution and management functions.

The Planning Process under Change

The planning process that the US will implement and use in the SINCE experiments still contains all of the components that are associated with the standard deliberate military planning process. The deliberate military planning consists of a sequential process which steps in a serial manner through mission analysis, COA development, COA analysis, COA comparison, COA briefing and selection, Operations Plan (OPPLAN) and Operations Order (OPORDER) preparation and dissemination, mission rehearsal, and finally into mission execution, monitoring and re-planning. In a future 2010 world of the Objective force/ FCS, these planning process steps will be performed differently and executed in a more streamlined, reduced decision cycle timeline. Figure 3 below, conceptually illustrates the more streamlined, interactive and integrated military planning and decision making process that the US expects to have in place by 2010.

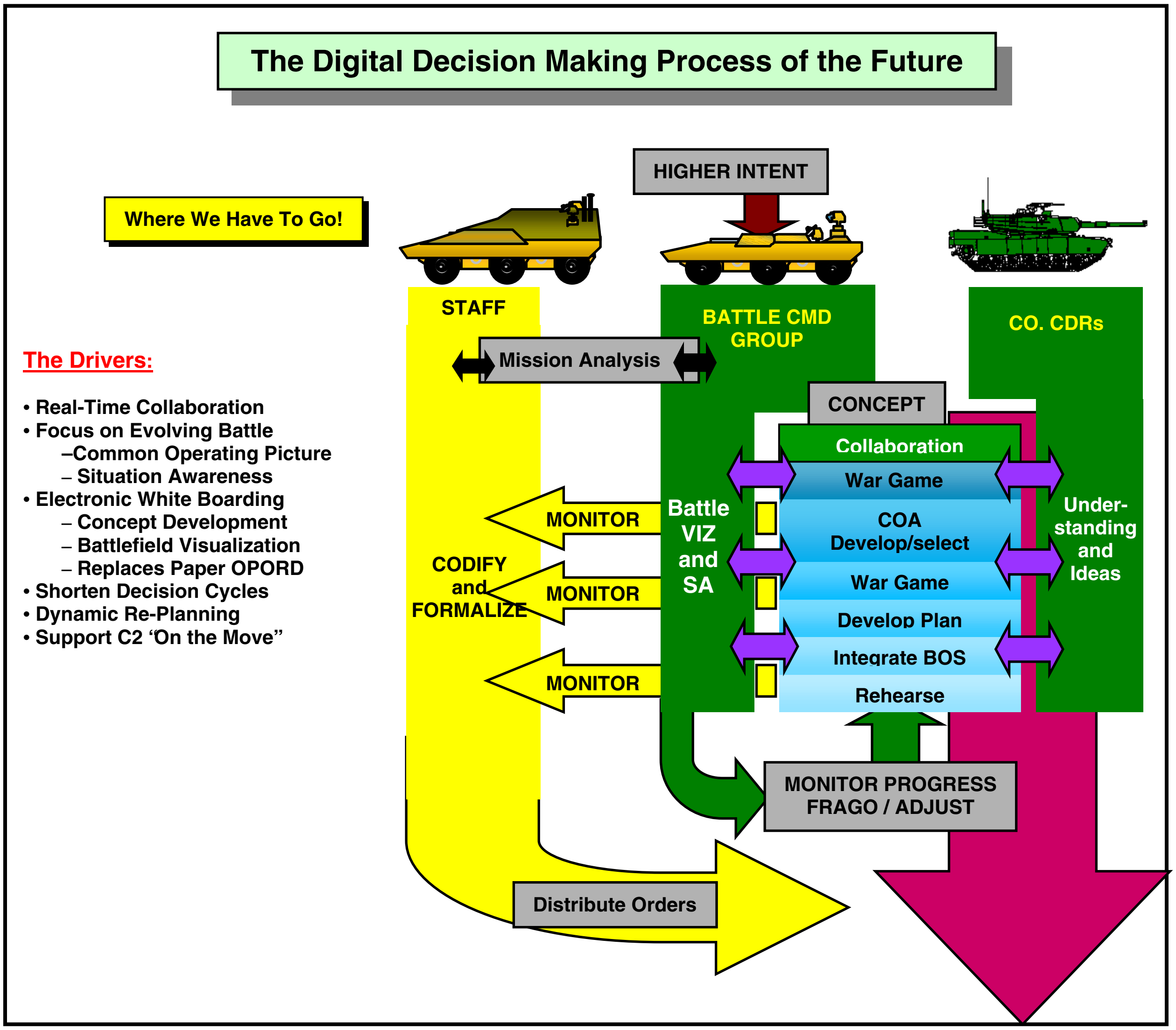

Figure 3: Streamlining the Decision Process

The use of accurate, real-time Common Relative Operating Picture (CROP) situation awareness information is essential to enabling our future commanders to perform these functions in the envisioned streamlined manner. However, our coalition partners may not employ the same digitized C2IS and decision support capabilities that the US expects to have in place by 2010. In the SINCE effort, the US will experiment on how to bridge this real gap between two businesses needing to work together but using different business paradigms. Many of the

next generation Mission Planning, Mission Execution, Dynamic Re-Planning and Mission Management Decision Support Tools that the US will be using in the SINCE program are currently in development in the CECOM Agile Commander Advanced Technology Demonstration (ATD) program. These evolving products will be transitioned both into the current Army Battlefield Command System (ABCS) and also the future Objective Force/FCS C2IS. The Agile Commander Tool Kit represents a modular set of scalable, US Army Defense Information Infrastructure-Common Operating Environment (DII-COE) compliant, decision support tools that can be used and customized to perform the indicated types of functions throughout all of the different echelons of the ARMY. SINCE expects to use these Agile Commander products in different information flow and business models/configurations, to support our experimentation activities. The Agile Commander **D**istributed **A**nalysis and **V**isualization **I**nfrastructure fo**r C4I** (DaVinci) collaboration server, infrastructure and multi-session administration service capabilities will be extensively used to support real-time collaboration between US and German participants in the conduct of the SINCE experiments. Figure 4 depicts the kind of planning and decision support functions and capabilities that are supported by Agile Commander DaVinci infrastructure.

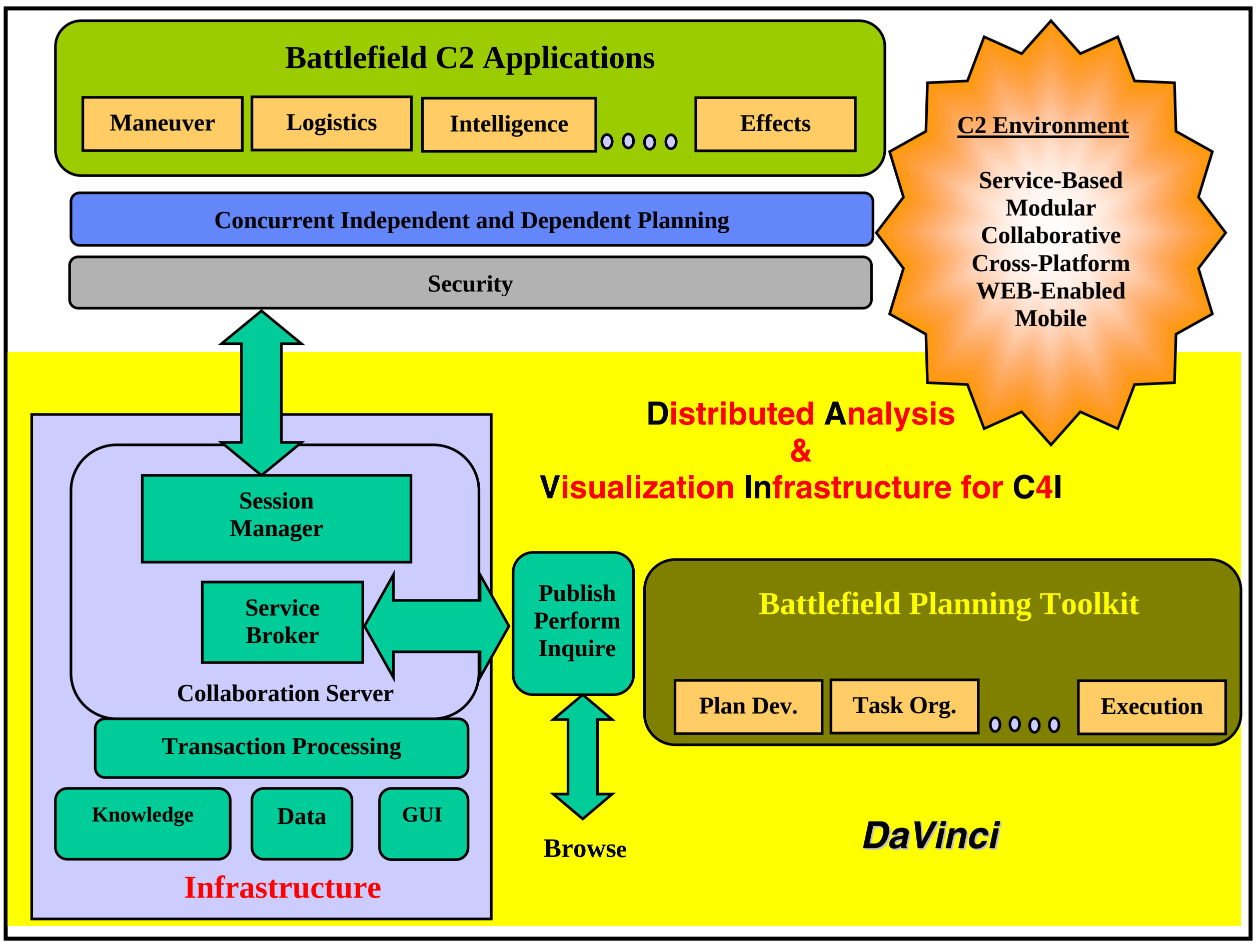

Figure 4: Agile Commander ATD Distributed, Collaboration Architecture

Leveraging the Interoperability Solutions of other International Fora

As indicated the SINCE Program focus discussion, this effort will use the interoperability solutions developed and implement by other international fora concerned with implementing information exchange interoperability between US and NATO C2IS. The Multilateral Interoperability Program (MIP) program is a

six nation effort that has been looking into and defining the Information Exchange Requirements (IER's) between coalition force C2IS. MIP has developed a common data model for both AdaptP3 message exchanges and the Army Tactical Command and Control Information System (ATCCIS) database-to-database replication exchanges. Figure 5 below conceptually describes the kinds of information exchange the MIP solutions support. MIP Information Exchange Requirements (IER's) can be met via 16 different AdatP3 type formatted messages or their equivalent ATCCIS Generic Hub 4 data representations. SINCE will use both of these solutions to implement information exchange services to support SINCE experimentation. The MIP ADatP3 message exchange solutions are scheduled to be demonstrated/ field tested late in the 2001 calendar year. The MIP/ATCCIS data base replication solution is scheduled for testing somewhere in the FY 2003 timeframe. The information exchanged via the MIP IER's essentially represents CROP situation awareness type information. In the following sections of this paper, we will show how MIP solutions will be used in support of SINCE.

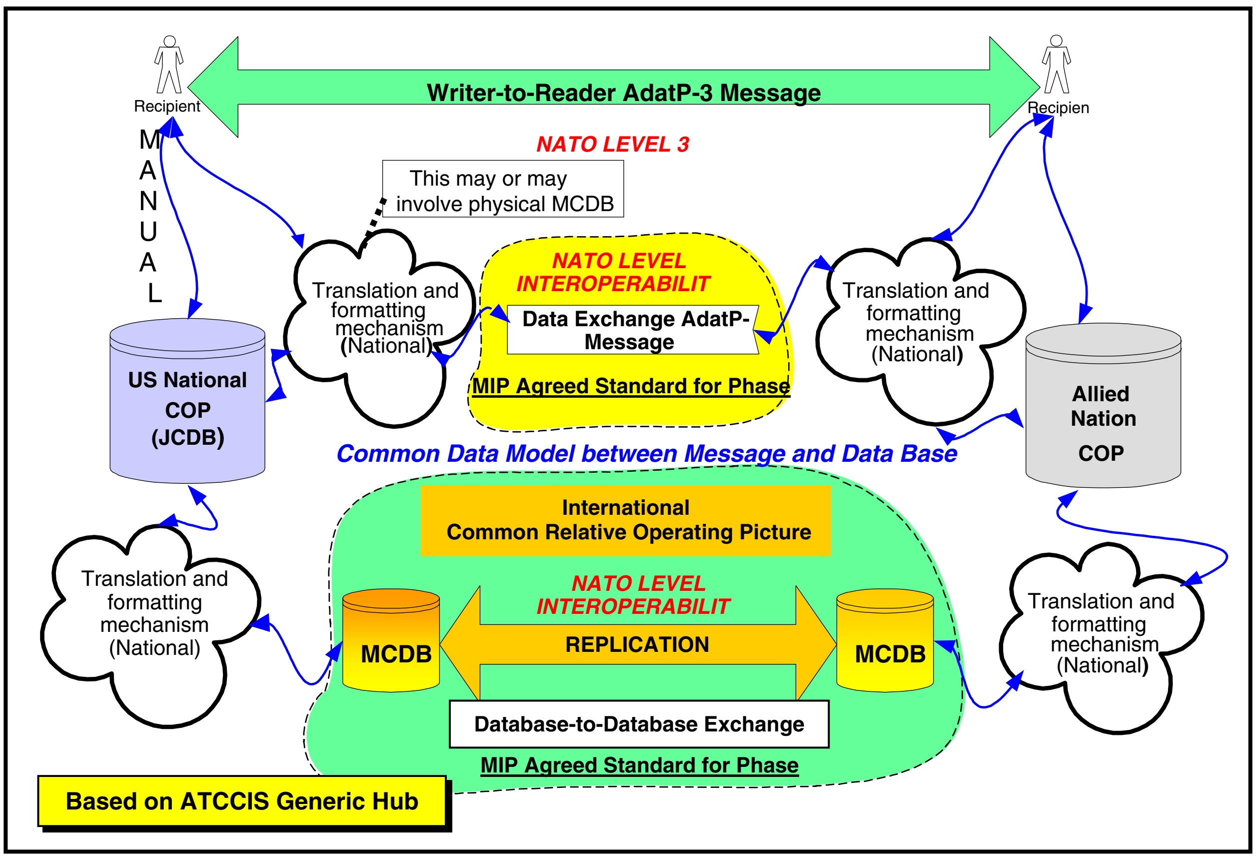

Figure 5: Multilateral Interoperability Program (MIP) Solutions

The SINCE Information Exchange Proxy Server

To support SINCE experimentation, both the US and Germany will nationally be networking federations of their national C2IS and appropriate M&S systems. Figure 6 depicts how the SINCE program expects to implement the exchange of the International CROP information between the US and German federations of C2IS and M&S supports systems participating in the SINCE experiments. Basically the SINCE Information Exchange Proxy server implements a real-time CROP database that is built during process of exchanging either real-time MIP AdatP3 message or ATCCIS Generic Hub 4, database-to-database contract exchanges. Each nation inputs and extracts, as necessary, the relevant CROP information to be exchanged between Coalition partners. The Proxy Server CROP database is being implemented using the MIP Common Data Model (MCDM). US C2IS will receive updates of this international CROP information either via

appropriate MIP ADatP3 messages or MIP database to database exchange contracts. Additionally, to support the participation of C2IS systems or their emulation, that do not have extensive message or database update handling capabilities, a Web based information portal view of the this coalition CROP is also being implemented via the SINCE Collaboration Server. The collaboration server will provide and support real-time coordination and synchronization activities between the coalition force planners and mission managers during the conduct of the SINCE experiments. While two separate transatlantic communication paths are indicated in this chart, in reality they will probably be multiplexed into one communication channel in the final implementation. Mirror copies of this CROP Data Base will be updated and maintained via an XML implementation of the of the ATCCIS Generic Hub 4 database-to-database replication mechanism. Note also, that the HLA based interface is also being implemented to enable the passing of CROP information to and from the simulation systems supporting the instrumentation of the SINCE experiments. This HLA interface supports the passing/update of coalition shadow force information contained International in the CROP database. This is needed to maintain ground truth in the simulation side of the experiments. The Common C3 Driver indicated in figure 6, is a US national unique interface for connecting US C2IS to US M&S systems.

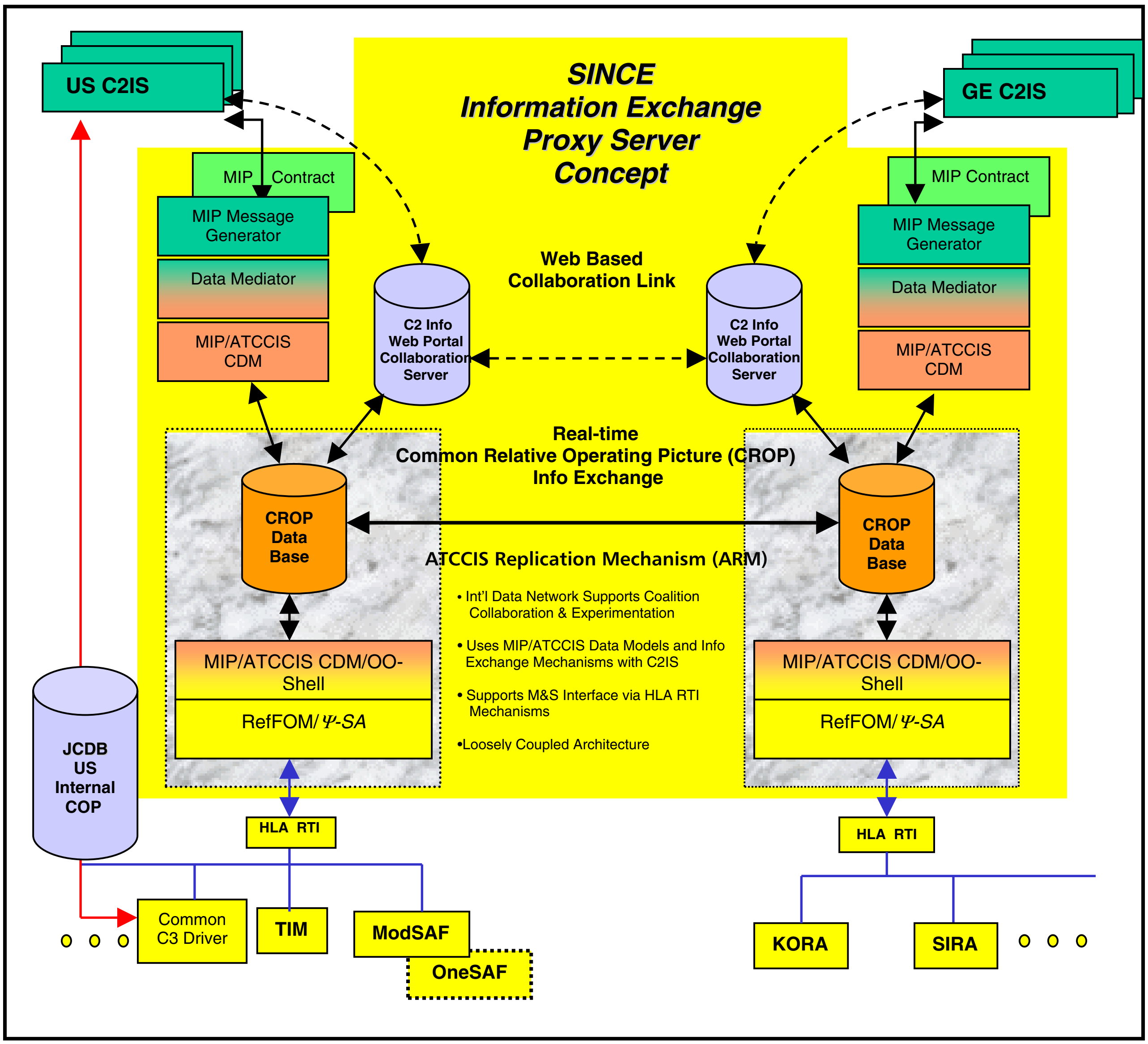

Figure 6: The SINCE International Interface

The US SINCE Command and Control Simulation Environment

The CECOM Command and Control Stimulation Environment (C2SE) being used to stimulate US SINCE experimentation supports the test and evaluation of new battlefield decision support aids, to include course of action analysis tools. The intent of this C2SE is to provide the development and test communities with the ability to simulate Command and Control Information Systems (C2IS) concepts and evaluate software performance, implementation of strategies, Doctrine, Tactics, Techniques and Procedures (TTP) and validate solutions that support the interoperability. Additionally, this stimulation environment provides a venue to train personnel on C2 systems, as well as to provide a portal to large-scale distributed simulations. C2SE represents an essential development environment, tailored to support the rapid prototyping and concept development capabilities needed to support the US Army Transformation initiative. In real-life, C2 systems under development are required to interact with both legacy and other systems in development. Playing evolving C2 capabilities in the CECOM C2SE, provides immediate feedback on the tested system's performance during the development process, and also tests how it will interact with fielded systems. The US simulation approach involves integrating the C2SE within the SINCE demonstration environment. To facilitate this integration, it was agreed that eXtensible Markup Language (XML) information tagging and encoding concepts would be used to support the implementation of an interface enabling information exchange between the C2IS and simulation environments. An initial, limited capability prototype demonstrator of this information exchange mechanism has been implemented to both validate the concept and evaluate throughput performance characteristics. This initial demonstrator only addresses the exchange of information that is typically contained in MIP AdatP3 Situation Report (SITREP) type of message or its equivalent ATCCIS database-to-database contract updates. On the C2IS system side of the US prototype Proxy Server, both representations of the MIP AdatP3 SITREP and equivalent ATCCIS contract exchanges can be functional received and generated. An XML version of a database server conforming to an ATCCIS Generic Hub 4 Data Model is used as temporary repository for both building the real-time CROP database and maintaining linkages/mappings between incoming /outgoing message and database-to-database contract constructs. Information exchange between the Proxy Server and the simulation world is essentially implemented via a High Level Architecture (HLA) Federation Object Model (FOM) interface. Effectively, the Proxy Server establishes an XML socket connection between itself and the C2SE and forwards to that socket XML tagged versions of the information received from a SITREP or any other message/data construct. An initial prototype of an XML parser capable of interpreting these XML SITREP message types and transforming them into appropriate HLA FOM representations has been implemented. This capability has been integrated within the C2SE to allow for sending and receiving XML formatted information constructs across the C2SE HLA interface. While the initial focus of this work addressed only the parsing of incoming/outgoing SITREP type of information, specifically unit type, identification and location, future efforts will significantly expand the type and scope of information to be exchanged to meet the support requirements of SINCE experimentation activities. Once the data has been translated into the HLA FOM representation it is made available to the OneSAF Test Bed Baseline (OTB) simulation via its interface HLA. This data is also stored in the C2SE Multi-Source Database (MSDB).

The US Distributed Experimentation Network

Figure 7 illustrates how the C2SE interfaces with the US SINCE Proxy Server in supporting distributive SINCE experimentation activities. The experimentation network and environment represented in this figure enables the US to economically and effectively link facilities, equipment and manpower resources at Ft. Monmouth NJ, Ft. Knox KY, and Ft. Leavenworth KS into a virtual, collaborative experimentation laboratory for use in SINCE. The CECOM Digital Integration Laboratory (DIL) supports a real-time, high bandwidth network to the indicated facilities, but will also be used to link to our German SINCE partners. As indicated in Figure 7 the C2SE controls and enables, for example, the information about simulated US Company level Armor Tank units at the to flow back up to both US C2IS and GE C2IS via the Proxy Server. The C2SE also accepts information about simulated GE Tank units via the Proxy Server, and updates GE unit shadow models in US simulations. The OTB database is being used to identify and set up terrain databases

suitable to support SINCE experimentation. This database can generate terrain background GIF files based on OTB terrain database. These files will be used as the map background for the SINCE demonstration Web Information Portal CROP browser and other US C2IS displays. Additionally, it should also be noted that information flowing between the Simulators and C2IS (both real and emulated) in the US SINCE experimentation environment will actually propagate through an enhanced version of the US Tactical Internet Model (TIM+) simulator, emulating a network-centric tactical communications environment. The intent here is to make the flow of information as realistic as possible and introduce the fog of war (errors, time delays and latency problems, and disconnects). Both the legacy ABCS and the emulated Objective Force and FCS C2IS will either have or be upgraded with an appropriate suite of Agile Commander Tools needed to support t SINCE experimentation. Each C2IS will also have a real-time collaboration and connection capability to their peers, both US and GE, or other international participants. However, this connectivity will also be subjected to the TIM+ environment to introduce real world emulated network conditions. To simplify and reduce the cost of implementing and emulating Objective Force/FCS C2IS planning and mission management cells, we expect to make extensive use of Web Information Portal concepts and to provide these cells with access to both national and international CROP information.

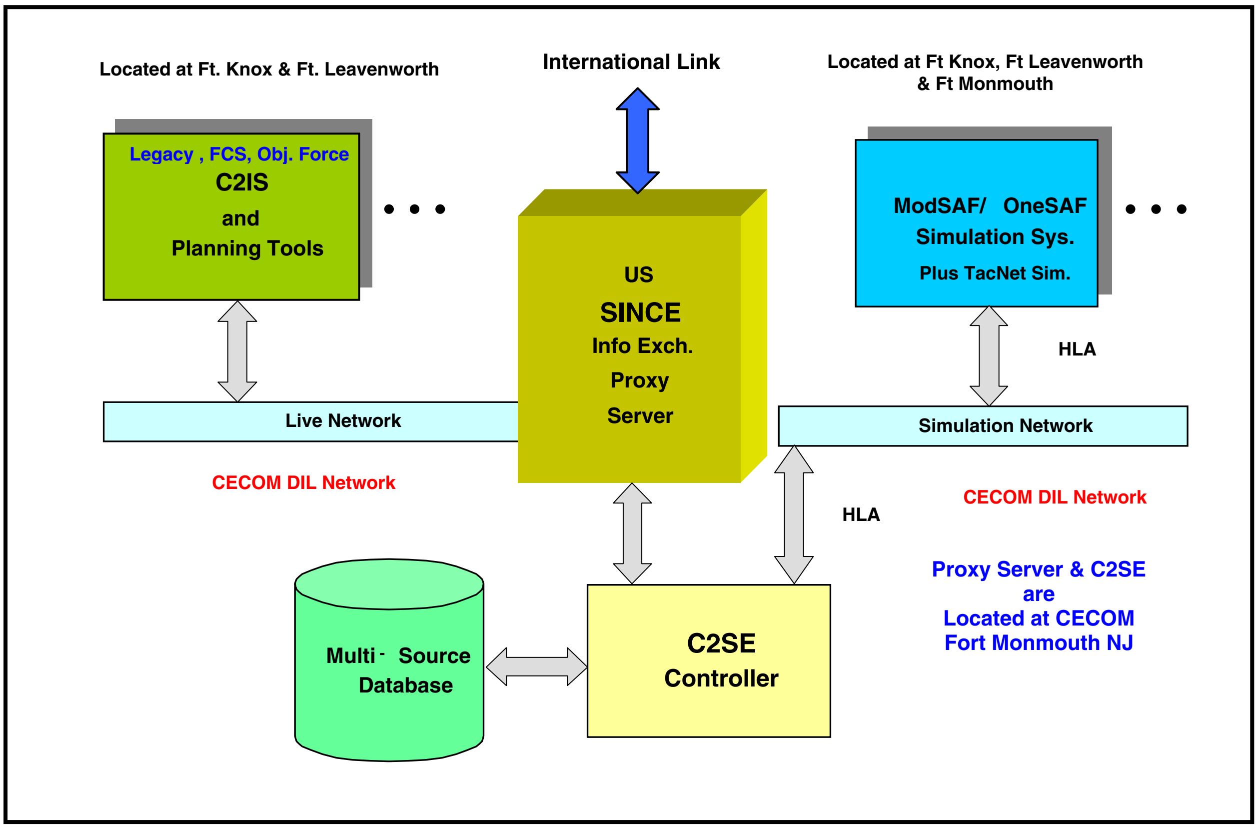

Figure 7: US Distributed SINCE Proxy Server /C2SE Distributed C2IS-Simulation Network

Emulated FCS/Objective Force C2IS Mission Planning & Management Cells

Figure 8 below, conceptually illustrates how the US expects to emulate FCS and Objective Force C2 Mission Planning and Management Cells. This chart depicts from a technical perspective the operational capabilities that emulated Objective Force/ FCS C2IS cells will have. The depicted C2IS architecture is a loosely coupled, web-based information system design that is tuned for network centric, execution–based C2. CECOM has been defining and prototyping this advanced C2 system architecture, over the past few years,

both in support of network-centric customer efforts and to facilitate integration of evolving technical products. It is cheap, high performance and very flexible. With the integration of the Agile Commander products, military users have a very capable and responsive C2IS. The purpose of this C2IS infrastructure is to rapidly pass real-time execution information to the right place at the right time, by passing many of the information flow blocks present in current legacy C2IS designs. Adding the appropriate suite of Agile Commander Decision Support Tools and Collaboration Services should allow us to inexpensively emulate the functionality/capabilities of future Objective Force /FCS C2IS. Note also, that both the Agile Commander ATD program, and the US Army Battle Command System (ABCS) Version 7 architecture have recently embraced significant elements of this C2IS infrastructure design concept for incorporation in their development efforts.

Four Phases of SINCE Experimentation

Figure 9 illustrates the planned SINCE program phases spanning across a 5 year period. All of these experimentation phases will play against different vignettes of a common Support and Sustainment Operation (SASO) scenario developed by our joint US/GE military user, Operational Working Group. The Phase 1 effort will heavily focus on the implementation aspects of the infrastructure and software support systems/capabilities required for the conduct all four phases of SINCE experimentation. Key thrusts for the Phase 1 effort are implementation and testing of mechanisms enabling the real-time exchange of coalition CROP information via messages, initial database-to-database contracts, and Web objects.

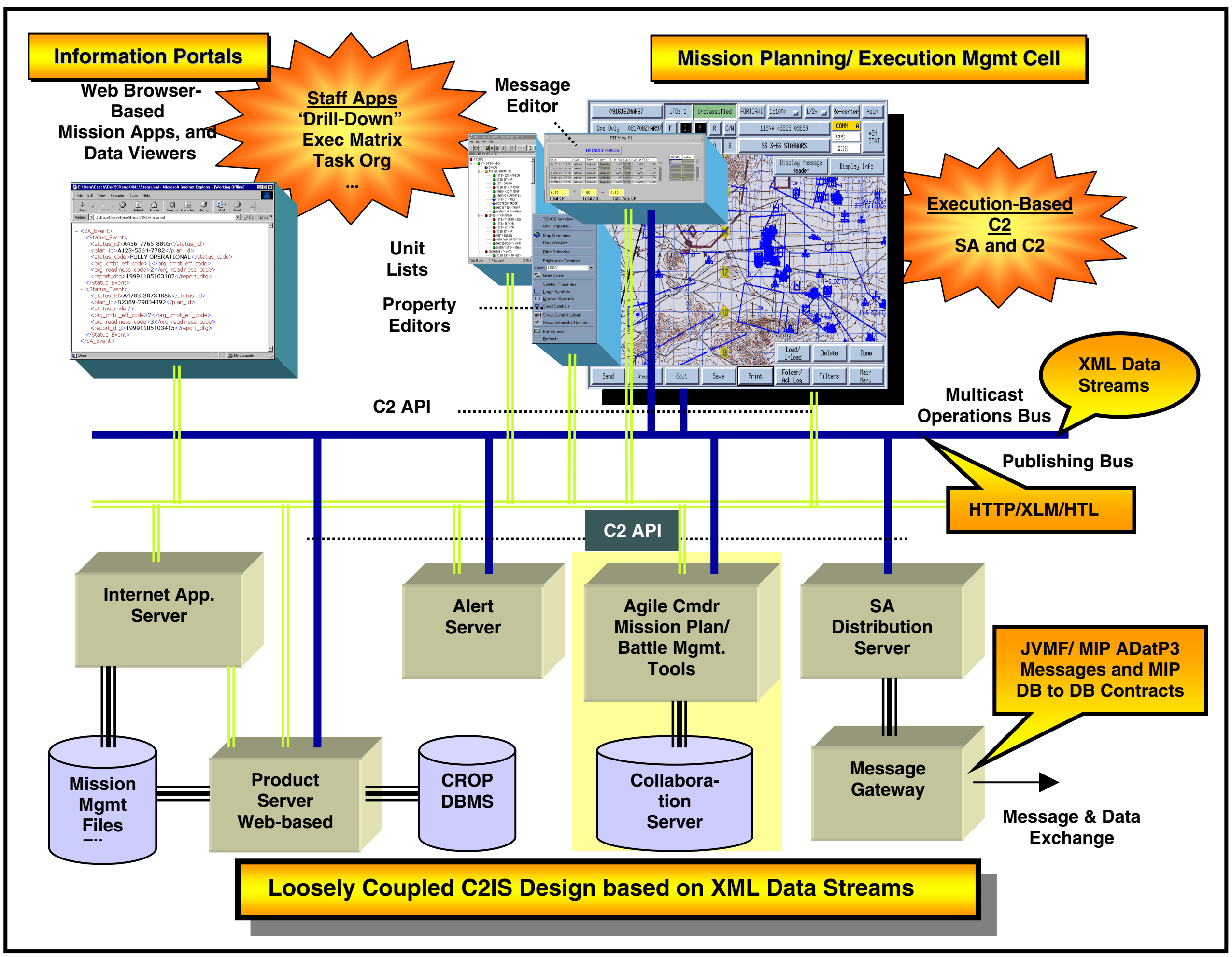

Figure 8: Web-based, Emulated Objective Force and FCS C2IS

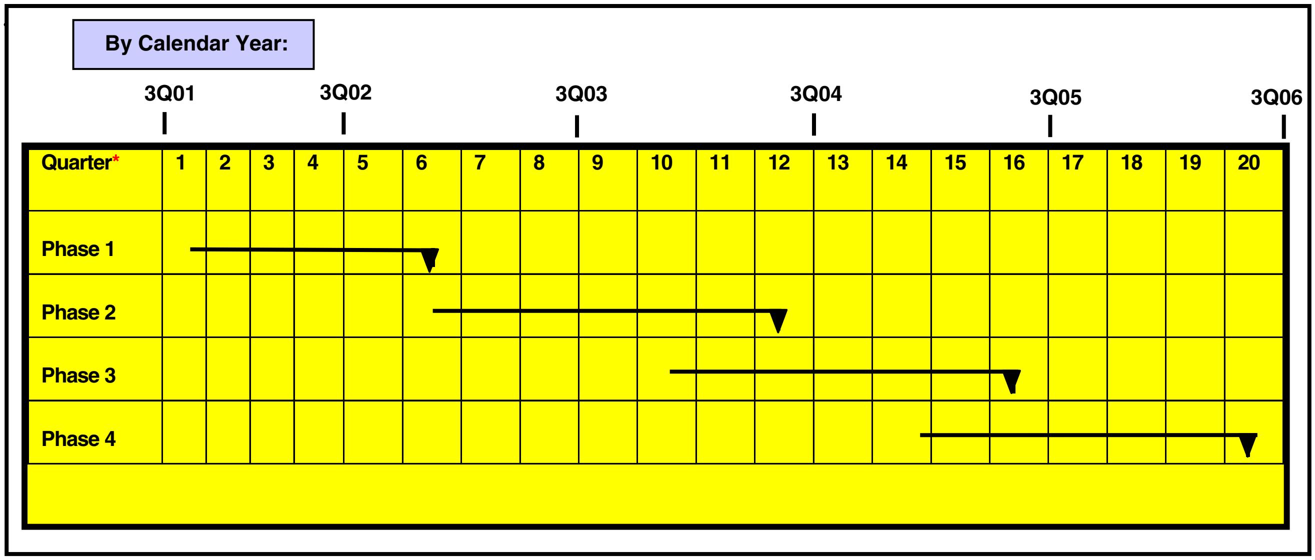

Figure 9: SINCE Experimentation/Program Schedule

From an operational perspective, the Phase 1 effort will focus on initial maneuver "On-the Move" Mission Planning and COAA. For the Phase 2 experiment, the operational focus will expand to include collaborative maneuver and initial Fires Planning combined with real-time, on going execution monitoring and dynamic execution re-planning activities. The Proxy Server's real-time CROP, MIP message, ATCCIS DB-to-DB, and Web-Objects will technically be expanded to support all of the types of information exchanges needed to support the Phase 2 interactive, collaborative mission planning/management activities. The SINCE Program management team plans to extend invitations to several NATO nations to be observers in the Phase 2 experiment. In Phase 3, the coalition maneuver and fires mission planning and execution activities will be expanded to include coordination with joint and coalition Air Force and Naval support activities. Technically the Proxy Server's information exchange capabilities will be significantly expanded to support these activities. Also in Phase 3, it is expected to see the entrance of other NATO nations as full time participants in the SINCE program and experiments. Finally, the Phase 4 experiment is expected to be equivalent in scale to a multi-nation Command Post Exercise (CPX). The number of operational vignettes exercised and derived from the SINCE SASO scenario will be significantly enhanced to reflect a diverse collection of simultaneously on-going activities both typical to traditional and unique to SASO coalition operations. The focus will be on more complex Mission Management activities, stressing short decision, planning and reaction cycles in a mobile, dynamic and multi-cultural coalition force environment. The precise details of the vignettes and technical details for each of these experimentation activities currently being worked by our US/GE Operational and Technical Working Groups. Based on the availability of appropriate Decision Support Products in both nations, manpower resources and funding, some of these activities may get shifted to different program phases, but the SINCE Program Management Group expects them all to be accomplished.

Summary and Conclusion

The key products and goals that the US expects will be demonstrated as a result of SINCE experimentation activities are a collection of internationally harmonized, tested and validated Mission Planning and Management tools/ decision support products. The tools/products are being developed to support the needs of current ABCS and future Objective Force/FCS commanders in the conduct of both traditional war and SASO coalition operations. We expect to transition these decision support tools/products to the appropriate US C2IS Program Manager/acquisition communities for incorporation into fielded and developmental C2IS. The solutions demonstrated and validated via SINCE experimentation will be compliant with evolving network centric, Objective Force/FCS Mission Planning, Execution & Battle Management concepts, doctrine, architecture and also the US Army DII- Common Operating Environment (COE). We also

expect to demonstrate, that the use of real-time collaboration, combined with enhanced visualization of real-time CROP situation awareness information, represents the enabling technology solution for successful conduct of future 2010 Objective Force coalition and Joint operations. Basically we feel that the combined use of real-time CROP Situation Awareness (SA) and collaboration techniques/capabilities is key to promoting better, common understanding of an Operation's execution between coalition force partners. SINCE will also demonstrate/evaluate interface mechanisms enabling C2 Information systems to use M&S systems in support of both COAA and the conduct of Coalition Force Mission Rehearsal. Additionally, as part of the SINCE effort, we will also demonstrate that evolving web-based information portal technology offers a cost effect means for enabling nations that do not have sophisticated digitized C2IS capabilities to successfully participate in and support coalition operations. Lastly, we also expect to specify, implement and demonstrate a common international interface that will allow other nations to easily and cost effectively participate in SINCE experimentation activities and future international CPX's. The SINCE experimentation environment and activities offers the US and its potential NATO partners, a unique opportunity to experiment with and refine future Coalition Force Operational Procedures and investigate alternate and new ways of achieving interoperability.

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The Tendencies of Modelling and Simulation Development in the Bulgarian Army

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Summary

This paper examines different aspects of the Modeling and Simulation application. The discussion about the development of this area in the Bulgarian Army is very important according to the reform and the National Program for Preparation and Accession to NATO. The future acquisition of modern defence systems is a new challenge for the Bulgarian Armed Forces. In the present context are emphasized the concepts and tendencies of the Modeling and Simulation field in the Bulgarian Army. This article is an attempt to give reasons for the necessity of Simulation Systems deployment to achieve a maximum interoperability and to prepare armed forces for participation in international joint operations and missions.

Introduction

Bulgaria's accession to NATO is a strategic objective for the country. The reform in the Bulgarian Armed Forces creates new challenges in the field of modern defence systems deployment.

The National Program for Preparation and Accession to NATO developed by Bulgaria, in co-operation with NATO and NATO nations, envisages [1]:

- Meeting the main interoperability requirements in key areas of co-operation by implementing both the Interoperability Objectives accepted within the PfP Planning and Review Process and all the Initial Partnership Goals.
- Introducing thoroughly a Defence Planning system that is compatible with the planning mechanisms in the framework of collective defence;
- Developing a modern, and interoperable with the Allies and NATO, crisis management system and command-control-computer-and-communication (C4) system;
- Developing operational capabilities for immediate response at battalion level in order to participate in multinational peace supporting operations led by NATO, WEU, or by a coalition of states;
- Developing pilot projects and build elements of a military infrastructure to provide logistic support to multinational formations, and ensure reception of foreign reinforcement assets and capabilities in line with the Concept Host Nation Support.

The National Defence System improvement and overall interoperability with NATO and the Partners are the two major policies for the present and future development of the Bulgarian Army.

The Bulgarian Armed Forces units are trained to participate in international joint initiatives including peacekeeping and peacemaking operations, and humanitarian missions.

An important element of this process is the modern command and control system deployment in the Bulgarian Army. In connection with this development is the training of basic command staff cadre according to NATO-standards [2]. That’s why the use of systems for computer-assisted training and education for different level staff and personnel is in unison with the contemporary tendencies in defence development.

Paper presented at the RTO NMSG Conference on “Future Modelling and Simulation Challenges”, held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

Arguments for the development of modeling and simulation systems

In this text the notion "system" is identified with the notion "computer system".

Nowadays the progress of information and communication systems is exercising a considerable influence on the modeling and simulation systems. The concepts of the contemporary modeling and simulation systems development are connected with the creation of common integrated environment for Command and Control Systems, Simulation Systems and Decision–Making Support Systems.

The tendency is to create standards for database, graphical user interface and geographic information system and to achieve a high level of unification.

The information and communication technologies support this process by means of new system approaches (object-oriented and component technologies [3,4]) and high-level architectures [5,6], models and protocols, software (middleware, languages [7], standard data bases, CASE-tools [8]) and hardware (computers, networks [9], multimedia, etc.). The network technology gives the tools to access data and software from different individual workplaces by sharing the resources and working in groups.

The models and simulations take part in different stages of system development under various forms [10,11,12].

During the stage of requirements definition are considered the problems of realization possibilities. The environment can be simulated and the interaction of different system approaches can be evaluated in such environment.

During the stage of system design a model of the whole system can be created for the evaluation of interconnections between components (which can be models themselves). There are developed the functional models, the resource usage models, information flows models, data models, etc. (Figure 1). Separate methods or algorithms can be analyzed through tracking models or effectiveness capturing models.

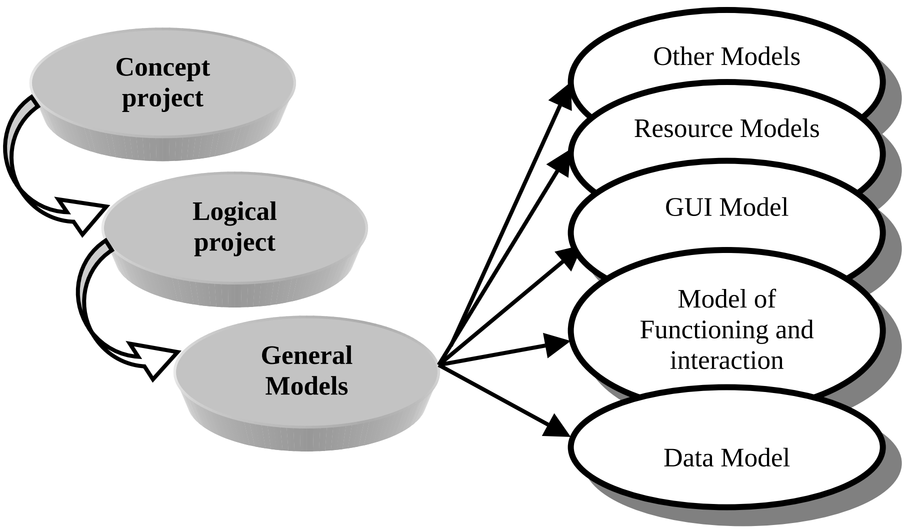

Figure 1.

During the stage of software design the simulations assist to find out and analyze processing problems – time correlation, delay, ranges of access, reference levels, which are related to reality.

During the stage of system acquisition the simulations imitate different types of system behavior according to the requirements. Besides, the simulations serve as a key tool in reducing the time to put the system into operation, in reducing resources, needed to evaluate that system, and in reducing decision risk. M&S also can provide a means to evaluate and improve the quality, military utility and supportability of the systems [13].

So, we can say that the models and simulations are applied in the whole life cycle of command and control (C2), planning and decision-making support system (Figure 2).

The Command and Control System consists of a tactical scenario model, including units, vehicles, convoys and other features, order-of-battle models, an airspace model, operations models, a model for force correlation assessment, etc.

Because a huge amount of information and knowledge of different data types has to be managed and processed in distribute communication networks, the military C2 systems have already acquired the qualities of information systems. The models of human interface are improved to provide a direct problem-oriented and/or object-oriented access to the information that is actually needed in the current operational situation. The command and control information systems (CCIS) possess a user-friendly interface in modern multimedia environments. A broad range of textual input and output details may be aggregated and transformed to other presentation models to support decision processes at the higher command level.

The defence planning process becomes more and more significant and the modeling is the tool to predict the results of different plans for defence resources management.

The Geographic Information System is a key part of each defense system and includes several models of the natural features of the country, of cultural and ground features in 3-D representation.

The analysis of the Modeling and Simulation usage above gives the possibility to notice several tendencies that are considered below.

Different approaches are applied during the system development. One of these is connected with the use of Modeling and Simulations on the stage of concept and abstract system design.

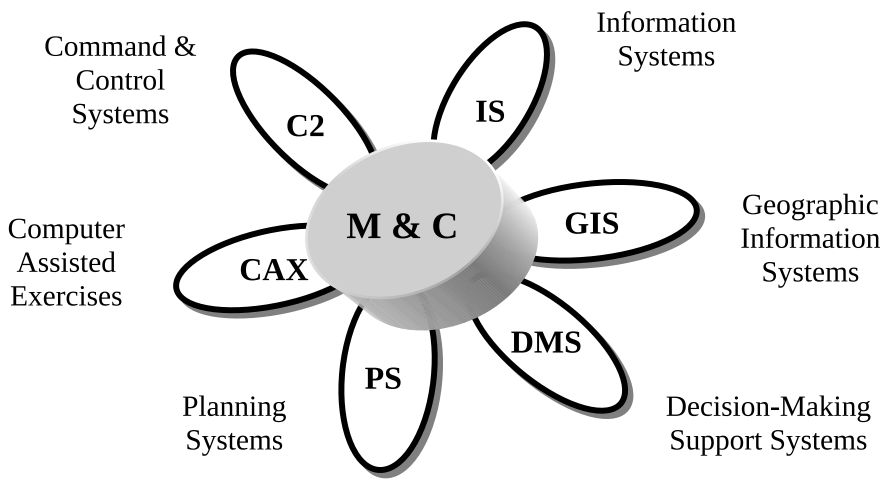

Figure 2.

- M&S are developed to solve some problems of real process research and investigation.

In this case the results are used as statistic information for process analysis, or later as elementary models in the project decision of the system.

- M&S are developed to clarify the structure or the functional relations in the system.

The idea of the structure and the interconnections between system components of the fielded system is generated on the stage of logical project. This model is developed to support the concept exploration and the definition phases of acquisition. M&S precedes system development. It is possible that the model loses the congruence with the system under development.

In these two cases the model allows to predict the results during the process. To obtain the valid answers it should present the process with the necessary and sufficient details.

- M&S support the system development.

Another approach demonstrates the benefits of parallel processing of simulations and system design. The researchers use the information obtained from analysts and system specialists to constitute the model. They

implement this model to obtain information for the designed system's behavior, further they give this information to the designers, who apply the results to improve the project.

The real system and the model are separate, distinct entities, but they are developed in parallel. The model guides the system development, and the developing system's test results refine the model.

- M&S are developed to provide some functional decisions by mathematical methods application. The model is a system subset.

This is the case when the real physical processes are being modeled by adequate mathematical methods. The model credibility depends on the precision of approximation of the process parameters interaction. These models become components of the system kernel and make for the system quality. But they also can be used independently.

So, all these models are not the end targets but only the tools to predict the proceedings of the simulating process.

A considerable interest provokes the approach when a newly developed system is a simulation. In this case the system hardware consists of the computer platform required to run the simulation. The system software consists only of the simulation. The simulation develops and improves until it becomes a system.

The logical bridge between the models and simulations entities and the aims of defence support systems confirms the necessity of the simulation technology application for system development.

Proofs of that are the requirements to the modern defence support systems:

- To provide realistic, exact and timely information for users;
- To serve as a tool for predicting the processes development;
- To give variants to support decision making of staffs;
- To create possibilities for training and education of units and staff in conditions maximum close to reality for the relevant operations.

With a view to the arguments presented above we can draw the following conclusions:

- M&S are a natural element (phase) in the life cycle of each system, particularly command and control (C2) or other defence system.
- M&S systems have an independent role under information environment creation - to reflect the relationships among information entities as well as information flow models, data models.
- M&S systems are the kernel of computer assisted training and education systems. Command staff training, group and individual training are performed through computer simulators and computer-assisted exercises (CAX).
- M&S systems support the activities of planning and decision-making policies, Defense Resources Management Models.

The development of modern modeling and simulation systems generates new requirements in the system acquisition. As new acquisition systems they require test and evaluation (T&E). As simulations, they require verification, validation and accreditation (VV&A). Since common points exist between these processes, it is important to combine two kinds of requirements to provide risk reduction and expense decreasing.

These problems are objects of the activities of MITRE Corporation programs [13], but they are not solved in the conditions of reform in the Bulgarian Army.

The comparative analysis of the military systems, especially information systems, C2 systems, training systems and systems supporting military policy and planning, presents the key role of M&S for all these activities.

There are **agents** that have an important role in modeling and simulation systems development and some of them are objects of this presentation.

During the last years the efforts of researchers and designers are directed to the creation of integrated information and communication environment, which combines command and control systems with the planning and decision-making support systems, and the training systems. At the basis of this challenge is the modern object-oriented and component technology and high-level architecture, distributed networks (Figure 3).

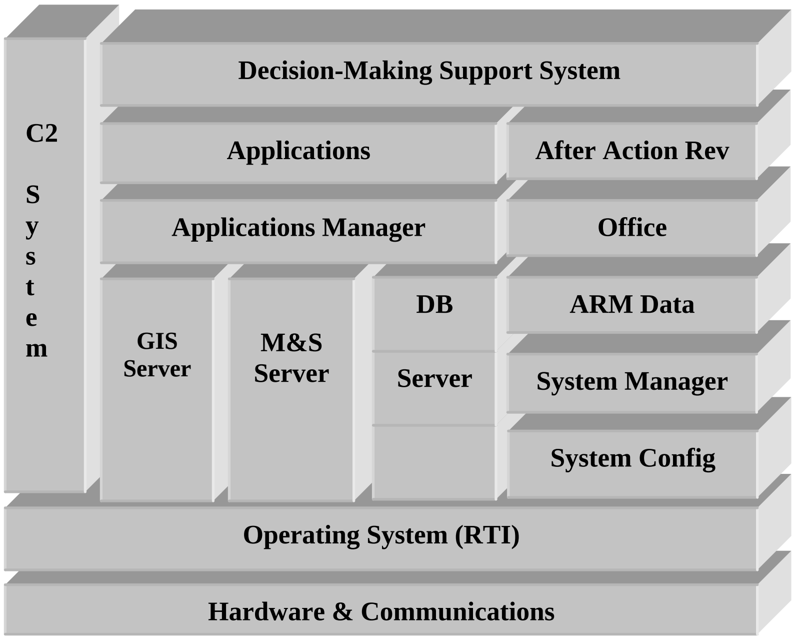

Figure 3.

The usage of simulation technology for training, operational decision support, and acquisition increases. Simulations are applied to evaluate emerging technologies and to analyze future tactics, doctrine, and concepts of operation. From an operational perspective, the increased presence of the computer on the battlefield as an integral part of Command and Control presents new challenges to the training of commanders and their battle staff.

Simulations support the Army by the creation of realistic synthetic environments that stimulate the Army Battle Command System with data that is representative of real world situations. This is a critical requirement to ensure the commanders are properly trained to exploit the information superiority that command and control systems are being designed to provide in the future.

Various simulations are designed to support tactical air and defense operations, to provide the military significant target sets, to represent the logical and physical networks, to create the realistic information flow to the audience through real world C4 systems. The Joint Simulation System is developed as a tool for future joint and service training, education, and mission rehearsal in all phases of operations – mobilization, deployment, employment, maintenance, and redeployment. The next generation battle staff models are created to support the readiness, the development of doctrine, and practice of operational art, situation evaluation, and the formulation, assessment, and rehearsal of operational plans.

Serious challenges occur for system designers and users in connection with various aspects of the interoperability [14].

The first problem is the operational interoperability. The new requirements for multi-national command structures in actual out-of-area missions - coalition warfare, peacekeeping and peacemaking operations and crisis management, change the situation. International missions have to be planned, prepared and executed in short time, in accordance with actual needs and this requires high flexibility and adaptability of command and

control information system. It is necessary that the military specialists and system developers work together on the stage of a conceptual project.

Another problem is the technical and technological interoperability among different simulations; simulators, live systems and simulations support tools.

The third aspect is the logical interoperability associated with the interaction of simulations on the logical level as well as with various modeling techniques in the applications and logical interpretation of shared data.

These problems are solved applying different approaches and system architectures to simulation systems development.

The modeling and simulation systems passed through different stages during the years – distributed system of models, Simulation Network, Distributed Interactive Simulation, but nowadays the High-Level Architecture is the fair way to solve the operational and technological interoperability problem.

The development of high-level technology stimulates the standardization in the “Modeling and Simulation” field and the reuse of models and their components [15].

From these preconditions result the possibilities for flexible support of simulation systems in their environment and direction toward next generation simulations.

The main idea, which is realized by the development and improvement of architecture of modeling and simulation systems, is to create and to execute integrated simulations in common information and communication environment, to achieve maximum interoperability and independence of applications and to reuse them.

What are the tendencies in the Modeling and Simulation field in the Bulgarian Army?

At the present moment in the Bulgarian Army are already introduced or are going to be introduced information systems, command and control systems, as well as planning support systems. In connection with Bulgaria’s participation in Partnership for Peace initiative and the Action Plan for accession to NATO there is a forthcoming process of putting these systems in conformity with the international standards and in particular with NATO-standards.

With the acquisition in the Bulgarian Army of the new systems arises a necessity of securing the respective interoperability level with the national defence supporting systems on one hand and with NATO-systems on the other hand.

This is going to be a complex and prolonged process having in mind the need to adopt and legalize the corresponding official documents as well as the carrying out of labor-consuming activities for development of appropriate system interfaces.

Based on the concept of simulation system usage for staff, armies and forces training, from 1995 to 1998 in the Bulgarian Armed Forces was put into operation a national Computer system for assisted exercises (tactical variant).

A series of computer-assisted exercises and land forces staff trainings were held that proved the effectiveness of such systems for increasing the quality of staff operational and combat preparation while lowering the costs.

The simulation systems and especially the systems for computer-assisted exercises are particularly topical during the reform execution in the Bulgarian Army and in the context of the National Program for Preparation and Accession to NATO, and also due to armed forces training for participation in joint operations and multinational missions.

In connection with these processes are the main directions of “Modeling and simulation” area development, namely:

- To define the main directions for development and utilization of the simulation systems;
- To establish common rules and frames in the training and to conduct exercises based on potentialities of computer systems;

- To create conditions for staff training maximum close to the really expected, which allow the work-out of command and control elements in order to successfully conduct military forces.
- To use the new information technologies, computers, warfare models, user interface and communications. To develop and examine the integrated simulations, simulators and live systems in a common information and communication environment;

The Bulgarian Armed Forces are in need of a modern simulation system for training force commanders and staffs in tactical, operational and strategic-theater joint tasks. That kind of system will supply operationally realistic conditions that include a synthetic environment, force representation and behavioral representation. An interactive, multi-gaming system will provide a joint and coalition force warfare environment on the base of air, ground, and naval combat models, with logistical, Special Operational Force, and intelligence support.

The expected effects of “Modeling and Simulation” area development are:

- Improvement of the quality and intensification of operative and battle preparation of staffs.
- Creation of conditions for staff work similar to those occurring during warfare and crisis.
- Decrease of the cost to accomplish the sufficient level of preparation and suit of staffs.
- Application of the new information and communication technology to staff work.
- Achievement of maximum interoperability in order to participate in joint operations.

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Developing Vehicle Survivability on a Virtual Battlefield

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Abstract

Modern anti-tank weapons and the requirement of rapid deployment have significantly reduced the use of passive armour in protecting land vehicles. This new development will eventually lead to replacing the main battle tank by a light armoured vehicle with at least the same level of survivability achievable through advances in sensor, computer and countermeasure technology to detect, identify and defeat potential threats.

The integration of various technologies into a Defensive Aids Suite (DAS) can be designed and analyzed by combining field trials and laboratory data with modelling and simulation of armed forces. This complementary approach will make an optimal use of available resources and encourage collaboration with other researchers working towards a common goal. A procedure has been developed, based on ModSAF (Modular Semi-Automated Forces), to analyze the performance of the DAS equipped vehicle on a virtual battlefield. Factors that influence performance can be placed in three broad categories and include environmental factors such as terrain and atmospheric attenuation, human factors, and the nature of the technology including sensor, countermeasure and algorithm effectiveness. ModSAF is being developed to analyze field trials and plan future trials more effectively, to analyze the effectiveness of a particular component or subsystem in various fixed battles and to provide the battlefield environment for a platoon of Hardware-In-the-Loop (HIL) simulators. The analysis of a specific DAS component can be undertaken more directly than has been possible in the past. Using this approach, the component can also be modelled phenomenologically to any degree required. The use of HIL simulators is important not only for training and crew development but also in developing the man-machine interface to specific DAS configurations. ModSAF is being used meet the challenge of developing a modular DAS configurable for a wide range of missions. The acceptance of this approach will require defining and meeting the requirements of not only the scientists who develop the technology, but also the operations research community and the military. Future applications of HIL simulators with ModSAF environments will include planning and training for specific missions and operations in the urban environment. These concepts and approach will be discussed in the paper.

Keywords: LAV, Defensive Aids Suite, ModSAF, operations research, Operations Other Than War, peacekeeping.

Introduction

Modern weapons have reduced the traditional effectiveness of passive armour on land vehicles. Portable missiles with warheads containing multiple shaped charges can penetrate practically any thickness of armour. Multiple sensor-fuzed munitions can be drop on to the target. Artillery, instead of rocket motors, can be used to launch guided missiles that cannot be detected by missile approach warning systems searching for rocket plumes. The solution is therefore to avoid detection as long as possible by camouflage and to reduce vehicle signatures to background levels. Survivability can be further increased by the early detection of threats followed by appropriate and timely countermeasures to either defeat the threat directly or to reduce the effectiveness of the guidance system.

A vehicle designed to survive these modern threats would rely less on passive armour and more on sensors, computers and other technologies. The long service life of the vehicle, typically 50 years, can also be a problem unless the vehicle is designed to accept upgrades. An approach to develop and maintain the survivability of the vehicle through a series of upgrades based on identified technological trends will be discussed in this paper. This modelling and simulation aspect to this approach can also be extended to estimate and improve the performance of test vehicles on the battlefield.

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

Survivability

Vehicle survivability can be represented in a series of layers as shown below in Figure 1. New vehicles designs would place a greater emphasis on the first two layers, detection and hit avoidance, to survive an attack. In the first layer, survivability is improved by reducing the size and silhouette of the vehicle and through signature management reducing to background levels emission in the following regimes, visible and infrared, radar cross-section, electronic, acoustic and magnetic.

The next layer, the DAS layer, relies on a system of sensors to collect data, which is then processed to determine the presence of any threats. This system is interfaced to countermeasures through processors, which will determine a prioritized list of responses. Hit avoidance is complicated by close ranges which results in short timelines, a dirty environment and numerous threats.

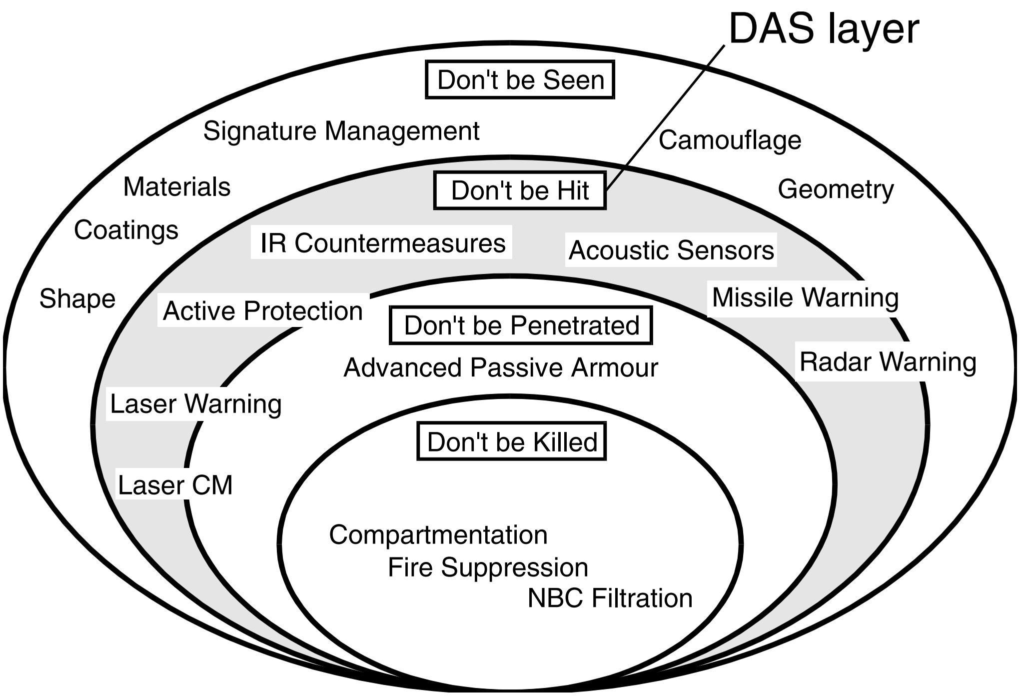

Fig. 1) Layers of Survivability

Among the many threats a list of 89 missiles was compiled in Table I according to the guidance and communication links used.[1]. Based on the total number of missile configurations, 26% (25 missiles) can be detected, and therefore countered, as laser-based threats. Of these threats 6 rely on laser designators, 16 of the missiles are beam riders and another 3 use either a laser based guidance or communications link. A total of 41 (43%) of the missiles are SACLOS and could be defeated by jamming the signal provided by the IR beacon to correct the missile trajectory. Therefore a combined laser-based threat and SACLOS countermeasure could be used to defeat a total of 66 missiles or 69%. Another 11 are of MCLOS design, the 2 ACLOS missiles are fired without operators, eight rely on a fibre-optic link for guidance, and seven are based on Imaging IR possibly a lock-on-before-launch design. The last missile in the list relies on RF illumination of the target.

In this list, missiles that rely on lasers may appear to be numerically less significant but are actually the more serious threat to the vehicle. Virtually all of the missiles have an operator in the loop to aim the missile at the target. Therefore an effective basic DAS could be based on laser detection, missile detection tracking and countermeasures including evasive manoeuvres, obscurants, dazzling and counterfire. This “soft-kill” solution can be effective but the large number and variety of threat missiles can make identification and therefore selection of appropriate countermeasures difficult. This difficulty can be overcome with a “hard-kill” solution, which will physically destroy the missile.

TABLE I

Threat Missiles Classified by Guidance or Communications System

Number	Missile Type
6	Laser and millimetre wave designation, including semi-active homing
16	Laser Beam Rider
3	Laser based guidance or communications link
41	Semi-Automatic Command to Line of Sight
11	Manual Command to Line of Sight
2	Automatic Command to Line of Sight
8	Fibre-optic guided missiles
7	Imaging Infrared
1	Radio Frequency Homing
89/95	Total missiles/Total configurations

DAS Development

Rapid deployment of the vehicle to a wide range of possible missions and low cost upgrading plays a significant role in the design of the DAS. Some of the strategies include “fitted for but not fitted with” where the vehicle is designed to accept a wide range of equipment but not fitted until necessary. Easier upgrading and resupply is possible through a “plug and play” approach. This level of readiness also facilitates rapid acquisition of up-to-date technology and further facilitates rapid deployment.

The DAS should be a federated, modular and mission configurable system, interfaced to the vehicle bus for access to other systems such as the Fire Control System. To keep the cost as low as possible the DAS based on more mature technology first and because of the rapidly evolving nature of technology. During the 50year service life of the vehicle, 5year upgrade cycles will ensure peak performance at a reasonable cost. The basic vehicle configurations described below do not preclude inclusion of other important systems such as sniper or bioaerosol detection and countermeasure. DAS evolution is represented in Figure 2, and could be carried out as follows:

Present LAV The LAV defence includes a laser-warning receiver with an angular resolution of one sector. The countermeasure is a NATO standard grenade with total effective obscuration achieved in 2s and persisting for 30s. The metal flake composition produces a spectral coverage from visible to long-wave infrared. ModSAF is used to model obscuration effectiveness based on terrain, wind and time after launch.

2005 Vehicle The 2005 vehicle will be a DAS-equipped LAV including automatic, semi-automatic and manual response of counterfire, countermanoeuvres and obscurants. The DAS will use the more precise HARLID™ [2] increasing the angular resolution from one sector to ±1°. The direct fire capability of the 25mm gun will be improved with a laser range finder.

2010 Vehicle The 2010 vehicle will be similar in DAS design as the 2005 vehicle described above. Improvements to the DAS will include communication with other vehicles in the platoon, dazzling or jamming of threats, and the use of an organic unmanned aerial vehicle equipped to detect land vehicles and other similar threats.

2015 Vehicle The 2015 vehicle will be a 2010 vehicle with a hard-kill capability. The DAS will be equipped with radar with a useful range of 500m. An infrared imaging system will be used with the radar to resolve threats with sufficient accuracy and precision. This information will be used to activate the

hard-kill countermeasure. A laser beam rider missile will be used as a kinetic energy weapon to improve LAV counterfire.

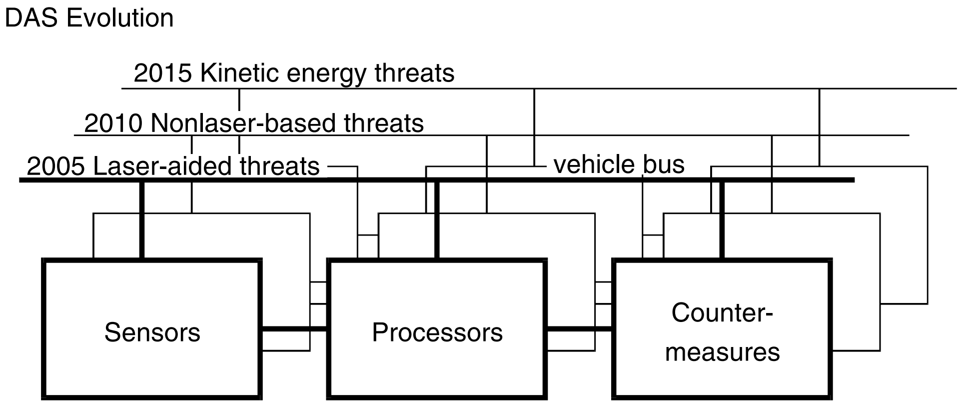

Fig. 2) Basic Components and Evolution of a Modular DAS system

Design Considerations

Analyzing threats, developing DAS technology and tactics, and crew training was at one time carried out with extensive investments in labs, field trials and field exercises. Increasing costs and reduced budgets require a much greater emphasis on modelling and simulation. Figure 3 depicts a typical timeline. The order of some events may change and some events may not occur or may not be strictly necessary, such as tracking or analyzing the threat situation, or even identification. There also may be several possible events of each type from different systems, in parallel. The events in italics are ones in which a human might play a role. With each event there is some probability of success that may be estimated against a given threat in a given environment. The timings are very important to determining whether a successful defence is even possible, while the component performance estimates will determine the extent to which the defence might be successful.

Modelling And Simulation

A Model-Test-Model cycle is difficult to establish for various reasons including, lack of information about foreign systems and incomplete models of the sensor and countermeasure environment. As shown in Figure 4, a continuous cycle can be established using field trials and experimental data to develop models and simulations. Ideally models should be based on physical principles but when this is impractical, systems can still be analyzed phenomenologically. Both approaches can be implemented in operations research codes such as ModSAF. ModSAF (Modular Semi-Automated Forces) provides a capability to define and control entities on a simulated battlefield. It is a model of the outward behavior of simulated units, their component vehicles and weapons systems with sufficient realism for training and combat development. ModSAF simulates an extensive list of entities including fixed and rotary wing aircraft, ground vehicles, dismounted infantry, and additional special models such as howitzers, mortars, minefields, and environmental effects. The behaviour of the simulated entities can be scripted so they can move, fire, sense, communicate and react without operator intervention. The entities can interact with each other as well as manned simulators, over a network supported by Distributed Interactive Simulation (DIS). Operating over a network is also useful in maintaining a necessary level of security. To gain general acceptance ModSAF development must meet the requirements of the scientists and engineers who develop the technology, the operations research community and the military developing tactics and doctrine. MATLAB, which is designed for quick-prototyping and code generation, can be used for ModSAF development. MATLAB modelling can also be shared with contractors and other researchers to facilitate the transfer of information. As shown in figure 4, an important application of ModSAF is the generation of a battlefield environment for Man-In-the-Loop simulators. The MIL simulators are critical in the development of a suitable Man-Machine-Interface for the DAS.

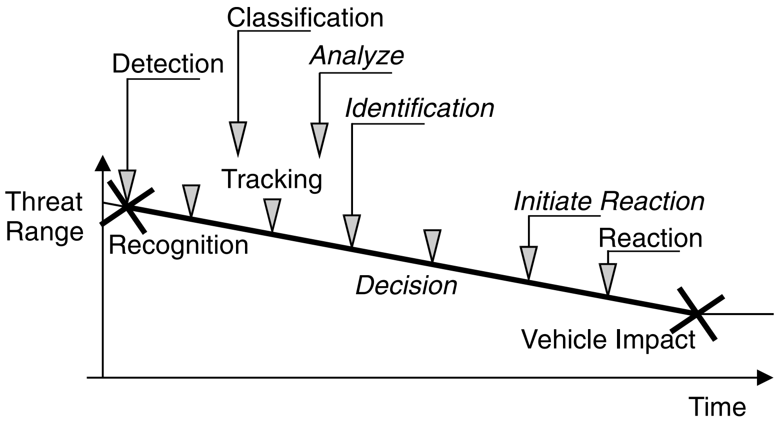

Fig. 3) Typical Event Timeline for Defence against Missile Attack

Another project, which can be analyzed in detail includes, technology development and evaluation through a parametric analysis. An engineering-level simulation is used to evaluate army systems or subsystems down to the individual soldier level, for current, future and virtual prototypes. Requirements include the ability to perform trade-off and parametric analyses with multiple variations of force structures, weapon system mixes and tactical implementations. ModSAF can also be used in the development of operational and organizational concepts and screening of initial weapons systems candidates for further study.

Current planning includes the eventual replacement of ModSAF by OneSAF. OneSAF will be a scripted, next generation computer generated forces (CGF) that can represent a full range of operations, systems, and control process from individual combatant and platform to battalion level, with a variable level of fidelity that supports all modelling and simulation (M&S) domains. Modelling will include specific activities of ground warfare (engagement and manoeuver), Command, Control, Communications, Computers, and Intelligence (C4I), combat support, and combat service support. It will also employ appropriate representations of the physical environment and its effect on simulated activities and behaviors. OneSAF will also have the advantage of executing the simulation in faster than real time and easier modification of input parameters.

ModSAF in this configuration can be used to analyze field trials and plan future trials and to estimate the performance of a test vehicle on a simulated battlefield. The information produced by ModSAF can be processed further with TOSOM[3] and ModIOS as shown in Figure 5. The Threat Oriented Survivability Optimization Model (TOSOM) has been developed to determine optimum DAS configuration for a specific mission. The development of optimum survivability strategies requires an assessment at both the force and system level. TOSOM provides a capability to, define a common threat environment for multiple system types, define encounter distributions at the force level and calculate an expected likelihood of achieving specific levels of force survivability. A typical result from this type of analysis would be the DAS configuration where “80% or more of the force must survive 72 hours of combat.” Notwithstanding some limitations, TOSOM provides a useful tool for investigating force level survivability. It helps fill a niche in the fairly sparse array of models and analytical tools available to address the optimum allocation of limited resources when designing or modifying combat systems.

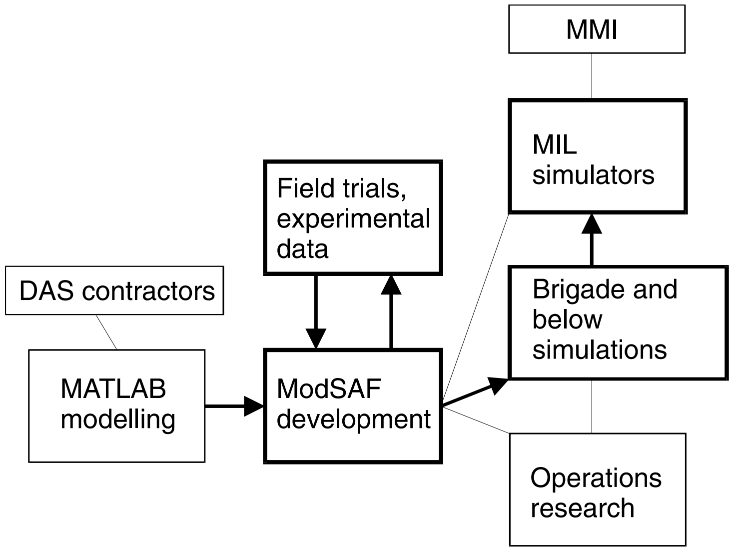

Fig. 4) ModSAF Development

ModIOS is a suite of tools designed specifically for ModSAF. It provides an HLA (High Level Architecture) interface extending ModSAF connectivity to other HLA compliant models. The various components in the suite include, Network Interface Unit Software to build HLA compatible federations, After Action Review Stations with a datalogger to perform a detailed analysis of the battle, Stealth Viewers, Instructor Operator Stations, and a Distributed Exercise Manager.

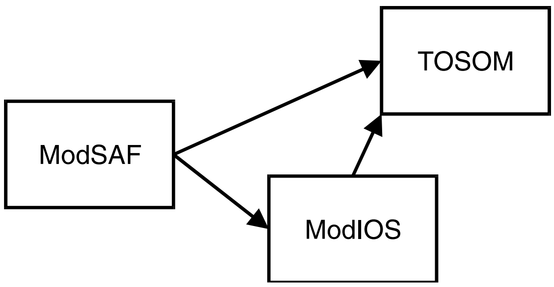

Fig. 5) Postprocessing Using TOSOM and ModIOS

The complexity of the models can result in enormous quantities of information generated but some of the more important events are depicted in Figure 6. The objective is generally to estimate the performance of the vehicle on the battlefield. Actual vehicle performance, defined as a combination of survivability and lethality, will have to be validated through field trials but the relative performance can be a useful indicator. One application is a cost-benefit analysis of proposed improvements. Another event of interest to many is the replacement of a Main Battle Tank (MBT) by a light armoured vehicle with improved direct fire capability.

Modelling physical systems in ModSAF

Modelling physical systems in ModSAF is not new. Terrain features are represented in sufficient detail to study vehicle mobility, detection, defilade and other practical manoeuvres. Atmospheric phenomena are modelled to produce accurate effects of attenuation over distance, scattering by smoke and dust and insolation. Spectral effects in the atmosphere, such as propagation of artificial sources in the solar-blind ultraviolet regime, natural effects such as solar glint and complicated, variable missile signatures are also modelled.

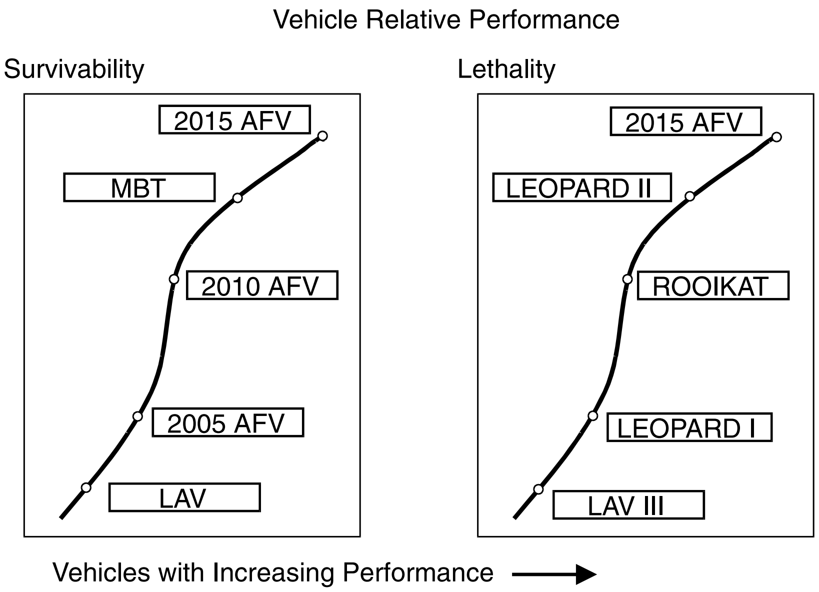

Fig. 6) Estimate of Vehicle Performance on the Battlefield

The combination of increasing computer power at low cost and the robustness of ModSAF can be used to represent vehicles more realistically in close-to-real environments and evaluated more thoroughly before field trials are carried out. Better materials and design can improve any weapon system. ModSAF can be used long before the new system is fielded to develop new tactics and doctrine. The following example describes some variables, including stochastic variables, encountered in modelling a high-speed beam rider missile intended to improve the firepower of an existing LAV.

Missile Evaluation Environment

The missile is designed to accelerate a high-density projectile, 0.5m long, to a velocity exceeding 2000m/s. The velocity is chosen to defeat soft-kill countermeasures by reducing the response time as much as possible and maintaining sufficient kinetic energy to penetrate MBT armour at the range limit of the MBT main weapon. A typical engagement is shown in Figure 7. Due to the effort needed to develop a safe and reliable weapon, the missile is expected to be available for the 2015 vehicle described below. A realistic evaluation would require that both the LAV and MBT be equipped with technology available for that time period. The MBT defence is based on the hard kill system, AWiSS-K, designed by DIEHL Munitionssysteme to stop kinetic energy penetrators.

VARIABLES AFFECTING MISSILE LETHALITY

To avoid using a future vehicle to fight a present threat, the 2015 LAV is matched with a 2015 MBT. The MBT is assumed to have the following capability.

Threat Detection and Tracking:

The beat performance is expected from a combination of radar for velocity data and a high-resolution staring array for more precise angular position.

Radar limited to a range of 500m to avoid detection. The initial missile velocity and direction are measured to within ±22m/s and ±1millirad, respectively.

IR imagery based on a system of infrared focal plane arrays with hemispheric coverage with effectively 4096x4096 pixels per corner. Detection algorithms will be used to alert the crew or automated system of MBT-like objects within range. It will be possible to detect and observe the orientation of the missile launchers and provide an early warning of a possible threat.

Countermeasure before missile launch: By detecting the turret-mounted launchers the MBT can react before the missile is launched.

Dazzling: Before effective obscuration occurs, which is about 2s for a NATO standard grenade, dazzling can be used to disrupt aiming.

Obscuration: Obscuration grenades based on a metal flake design can be used from visible through long wave infrared.

Radar and IR imagery provide an estimate of the missile position, which is then used to aim the explosive charge. The AWiSS-K grenade is designed to explode at a fixed distance of 50m from the MBT launcher. It is possible to compensate for any systematic lag but there are still random variables that can affect the position and detonation of the explosive charge.

Countermeasure of launched missile: The DIEHL Munitionssysteme AWiSS-K is designed to deflect or destroy the missile. The explosive charge has a propagation velocity estimated at 2000m/s, but several variables can effect the positioning of the blast wave.

Grenade: variation in time to achieve maximum thrust, <10ms.

Explosive charge: variation in ignition lag time, <10ms.

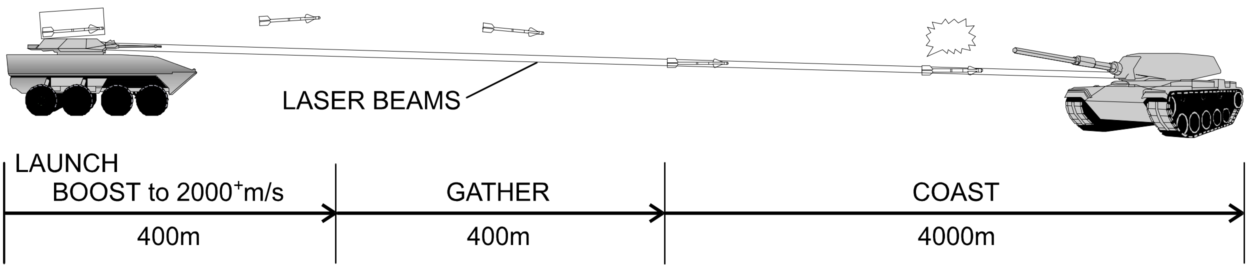

Fig. 6) Beam rider flight illustrating the laser beams used to guide the missile. To keep the guidance path clear, the missile is launched away from the laser beams until the propellant is burned out. The missile is then gathered and guided to the target. The MBT (right), using the AWiSS-K system, launches an explosive charge to deflect or destroy the missile.

Concluding Remarks

A procedure has been outlined to improve the development of DAS technology by combining prototype development and field trials with modelling and simulation based on operations research codes and off-the-shelf software tools. This new capability will provide a better estimate of vehicle performance on the battlefield and lower the cost of DAS development by complementing existing MIL facilities.

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Modelling of Combat Actions via Fuzzy Expert System

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Abstract. *In this paper we describe new approach for modelling of combat actions – via fuzzy expert system. We will comprehend two combat actions in our paper – battle dynamics between two opposite sides with Lanchester and Dinner equations. First, we will describe classical mathematical models of these combat actions. After it – we will define two expert systems containing different rule bases, which give an alternate solution for the decreasing of the number of combat units and for initial fire power. We will identify fuzzy rules for these combat actions, fuzzy variables and accompanied fuzzy sets. In the second part of the paper – we will focus on evaluation of the rules from the fuzzy knowledge bases, and obtaining of appropriate output variable possibility distribution, as well as it's defuzzified (crisp) value. We will show some simulation results obtained by Matlab's Fuzzy Toolbox, and compare them with the classical mathematical models of these two combat actions. In the last section of this paper – we give an overview of a reasoning expert system we have developed and implemented in Visual Basic. It is based on fuzzified Petri nets, with rule-based decision-making and appropriate knowledge base (KB).*

INTRODUCTION

The process of shooting is action with all type of weapon in order to cause damages to the enemy. The process of shooting can be modelled as a part of whole combat action, or separately, with analysis of different parameters. We can estimate the efficiency of our shooting without considering of enemy's action, or to perform dynamic estimation – with taking into consideration the enemy's action (more complex case). The study of shooting process emphasises two types of problems:

- Direct shooting problem, - estimation of shooting efficiency in given conditions;
- Inverse shooting problem, - determining of conditions which will provide maximal shooting efficiency.

The general model of shooting process consists the following elements: target properties, type of shooting, law for target hitting, dispersion characteristics, reliability, enemy's contra-attacks, target mobility etc. From the general model we can obtain several simplified models, which can be used for creating of mathematical models for combat processes. Such examples are:

- Shooting of immobile separate target – the efficiency in this case is equal to the probability of hitting the target;
- Shooting of group, area target, - the efficiency in this case is mathematical expectation of the number of hit targets;
- Creating of shooting process model with taking into consideration the enemy's actions;
- Creating mathematical model of combat dynamics.

The efficiency depends from the parameters of the shooting, and sometimes it is necessary to perform statistical modelling of the process by Monte Carlo method.

In this paper we describe another approach for modelling of combat actions – via fuzzy expert system. We will comprehend two combat actions in our paper – battle dynamics between two opposite sides with Lanchester and Dinner equations.

First, we will describe classical mathematical models of these combat actions. After it – we will define two expert systems containing different rule bases, which give an alternate solution for the decreasing

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of the number of combat units and for initial fire power. We will identify fuzzy rules for these combat actions, fuzzy variables and accompanied fuzzy sets. Fuzzy rules serve to describe, in linguistic terms, a qualitative relationship between two or more variables. Processing of fuzzy rules or fuzzy reasoning provides a mechanism for using fuzzy rules to compute the conclusion to given input propositions.

In the second part of the paper – we will focus on evaluation of the rules from the fuzzy knowledge bases, and obtaining of appropriate output variable possibility distribution, as well as it’s defuzzified (crisp) value. We will also show some simulation results obtained by Matlab’s Fuzzy Toolbox, and compare them with the classical mathematical models of these two combat actions.

In the last section of this paper – we give an overview of a reasoning expert system we have developed and implemented in Visual Basic. It is based on fuzzified Petri nets, with rule-based decision-making and appropriate knowledge base (KB). The reasoning algorithm is consisting of calculating the degrees of fulfilment (DOFs) for all rules of the KB and their assigning to the places of the Petri net. After this, it follows reasoning process with firing of active transitions and calculating of DOFs for output places (propositions of KB) and determining of fuzzy-distribution for output variables, as well as their defuzzified values. This development of our own reasoning system - is main contribution of this paper.

MATHEMATICAL MODELLING OF COMBAT ACTIONS

The Poisson distribution of the shooting process can be applied in the analysis of the battle dynamics between two opposite sides. We can assume that two opposite sides have: side 1 – N_1, side 2 – N_2 same-type combat units (weapon, soldiers, air-plane, etc.). Let side’s 1 combat units can annihilate side’s 2 units with probability p_1, and side’s 2 combat units can annihilate side’s 1 units with probability p_2. Shooting process for this example has Poisson distributions with density λ_1 and λ_2. The information for enemy’s combat unit annihilation is immediate – when the unit is destroyed – the fire is redirected to another unit. The missile flying time can be neglected in comparison with battle duration. Our task is to determine the probability $p_{kl}(t), (k = 0, 1,\dots, N_1; l = 0, 1, \dots, N_2)$ – that in the moment t – side 1 will remain with k, and side 2 – with l un-destroyed combat units. In order to interpret the mathematical model and solution for the given problem, we will define some terms. The combat unit’s effective shooting velocity can be defined with the products:

$$\begin{aligned} \Lambda_1 &= \lambda_1 p_1 - \text{for 1-st side,} \\ \Lambda_2 &= \lambda_2 p_2 - \text{for 2-nd side,} \end{aligned} \tag{1}$$

which denote the Poisson distribution densities for destroyed combat units in one unit of time. Further we can determine the probability that in infinity small time interval (Δt) each group will not perform or will perform only one shooting which will destroy enemy’s unit. Since – shooting distribution for all units is Poisson – the total distributions will also be Poisson – with distributions: $\Lambda_1 N_1$, i.e. $\Lambda_2 N_2$. So – the probability that side 1 won’t have successful shooting in time t will be:

$$p_0^I = e^{-\Lambda_1 N_1 t} = 1 - \Lambda_1 N_1 \Delta t \; ; \tag{2}$$

and the probability for one successful shooting is:

$$p_1^I = 1 - e^{-\Lambda_1 N_1 t} = \Lambda_1 N_1 \Delta t \; ; \tag{3}$$

By similar reasoning – for the side 2 we can obtain:

$$p_0^{II} = 1 - \Lambda_2 N_2 \Delta t \; ; \qquad p_1^{II} = \Lambda_2 N_2 \Delta t \tag{4}$$

If we consider combat dynamics as system transition from one state to another – than the system can be characterised with state A_{kl}, where k is the number of side’s 1 saved units, and l - the number of side’s 2 saved units. If we denote with $p_{kl}(t)$ – probability that in moment t the system will be in state A_{kl} – than the

system will be in initial state $A_{N1\ N2}$ if three events occur simultaneously: system was in state $A_{N1\ N2}$ in the moment t, and in time Δt – both sides didn't perform successful shooting. On this basis – we can write:

$$p_{N1\ N2}\ (t+\Delta t) = p_{N1\ N2}\ (t)\ p_0^{\ I}\ p_0^{\ II} = p_{N1\ N2}\ (t)\ (1- \Lambda_1 N_1\ \Delta t)(\ 1- \Lambda_2 N_2\ \Delta t)\ ; \qquad (5)$$

After few steps, we can obtain the following system of differential equations:

$$d\ p_{N1\ N2}\ (t)\ /dt = -\ (\Lambda_1 N_1 + \Lambda_2 N_2)\ p_{N1\ N2}\ (t)\ ; \qquad (6)$$

$$d\ p_{kl}\ (t)\ /dt = -\ (\Lambda_1 k + \Lambda_2 l)\ p_{kl}(t) + \Lambda_1 k\ p_{k,l+1}(t) + \Lambda_2 l\ p_{k+1,l}(t)\ ; \qquad (7)$$

for $0 < k \le N_1;\ 0 < l \le N_2$ and:

$$d\ p_{k0}\ (t)\ /dt = \Lambda_1 k\ p_{k1}(t),\ for\ k<0 \qquad (8)$$
$$d\ p_{0l}\ (t)\ /dt = \Lambda_2 l\ p_{1l}(t),\ for\ l>0$$

Initial conditions for this system equations are:

$$P_{N1\ N2}\ (0) = 1,\ p_{kl}\ (0) = 0,\ (k \ne N_1,\ l \ne N_2), \qquad (9)$$

under the general condition: $\Sigma_k \Sigma_l\ p_{kl} = 1$.

With integration of the given system of differential equations – we can determine probabilities of the possible system states as function of time – so we can calculate:

a) the probability of the number of un-destroyed units for each side in any moment of time;
b) mathematical expectation (mean value) of the number of un-destroyed units for each side in any moment of time;
c) the probability for triumph for each side. The given differential equations completely describe the battle dynamics. It is necessary to mention here that the obtained system of equations is very large and can be solved only by computer.

In the process of resolving the tasks about battle dynamics it is not necessary to describe all system's states. It is enough to know mathematical expectation (mean value) of the number of un-destroyed units for each side in any moment of time. Calculating the mathematical expectation of the number of un-destroyed units for each side – we obtain the Lanchester equations.

We start with the assumption that in any time – firepower of each side is proportional with the mean value of the number of un-destroyed combat units. The solution, which is based on this assumption, will be more precise if the number of un-destroyed units in the battle is quite large (more than 30). It is obviously that mathematical expectation of the number of un-destroyed units from both sides will decrease with time, if the effective shooting velocity of both sides is higher, or the sides have saved more units. So – the increasing of mathematical expectation of the number of un-destroyed units for side 1 will be:

$$\Delta m_1 = -\ \Lambda_2 m_2 \Delta t \qquad (10)$$

where:

Λ_2 – effective shooting velocity of side's 2 combat units;
m_2 - mathematical expectation of the number of un-destroyed units for side 2 in the observed period of time.

When we take $\Delta t\text{->}0$, we obtain the differential equation:

$$dm_1/dt = -\ \Lambda_2 m_2 \qquad (11)$$

Similarly – we obtain and next differential equation:

$$dm_2/dt = -\Lambda_1 m_1 \qquad (12)$$

where:

Λ_1 – effective shooting velocity of side's 1 combat units;
m_1 - mathematical expectation of the number of un-destroyed units for side 1.

Since Λ_1 and Λ_2 are constants – the obtained differential equations are homogenous, linear differential equations, with initial conditions: $m_1(0)=N_1$, $m_2(0)=N_2$.

By solving of the Lanchester equations – we will obtain:

$$m_1 = N_1 ch\sqrt{\Lambda_1\Lambda_2}\,t - N_2\sqrt{\frac{\Lambda_2}{\Lambda_1}}\,sh\sqrt{\Lambda_1\Lambda_2}\,t$$
$$m_2 = N_2 ch\sqrt{\Lambda_1\Lambda_2}\,t - N_1\sqrt{\frac{\Lambda_1}{\Lambda_2}}\,sh\sqrt{\Lambda_1\Lambda_2}\,t \qquad (13)$$

If we denote:

$\nu = N_1 / N_2$ – the ratio between both sides number of units;
$\alpha = \Lambda_1 / \Lambda_2$ – the ratio between effective shooting velocity of both sides units;
$\mu_1 = m_1 / N_1$ – percent of side's 1 destroyed units;
$\mu_2 = m_2 / N_2$ – percent of side's 2 destroyed units;
$\tau = \sqrt{\Lambda_1\Lambda_2}\,t$ - relative time unit;
$\eta = \nu\sqrt{\alpha}$ - the dominancy coefficient of the side 1 over the side 2 ;

then we can rewrite previous Lanchester equations as follows:

$$\mu_1 = ch\ \tau - 1/\eta\ sh\ \tau$$
$$\mu_2 = ch\ \tau - \eta\ sh\ \tau \qquad (14)$$

For different values of the coefficient η – we can show the solutions on fig.1. If $\eta=1$ – then no one of the sides is dominant and then:

$$\mu_1 = \mu_2 = \mu = e^{-t} \qquad (15)$$

We can see from fig. 1 that always wins the more dominant side, since battle dynamics depends on dominancy coefficient η. Since $\eta = \nu\sqrt{\alpha} = \frac{N_1}{N_2}\sqrt{\frac{\Lambda_1}{\Lambda_2}}$, it is obviously that better solution is to increase the number of units, instead of their shooting velocity. The effective shooting velocity is also important, but with increasing of number of our troops - we can neutralise enemy's shooting velocity.

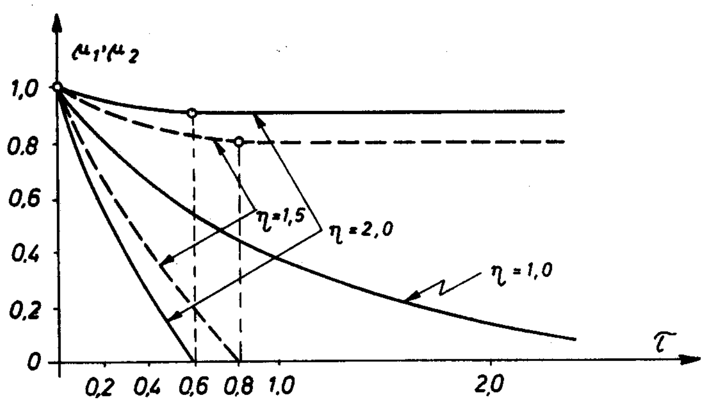

Fig. 1 – Lanchester equations solutions

Mathematical modelling of combat dynamics can take into consideration also combat objects, missile platforms, airports etc. The problem of this type can be formulate if we have following data:

N_1 and N_2 – side's 1 (side's 2) combat units, which are deployed on surface S_1 (i.e. S_2);
p_1 and p_2 – probability that area S_2 (S_1) will be hit by the units from side 1 (2);
λ_1 and λ_2- shooting velocities for both sides;
σ_1 and σ_2 – destroyed surface of appropriate side in one hit.

The deployment of the combat units on the surfaces S_1 and S_2 is unknown. The results from shooting are also unknown or they'll come with delay so it is not possible to redirect the fire from one unit to another. The problem consists of determining the number of un-destroyed units for both sides – in any time period.

Based on previous defined data - we can introduce the following terms:

$$U_1 = \lambda_1 p_1 \sigma_1 N_1 / S_2 \text{ – initial fire power of side 1;}$$
$$U_2 = \lambda_2 p_2 \sigma_2 N_2 / S_1 \text{ – initial fire power of side 2;} \qquad (16)$$

and in the begging of the battle their values will be $U_1\Delta t$ and $U_2\Delta t$. The fire power of the areas S_1 and S_2 is equal to the percent of un-destroyed surface, i.e.:

$$V_1(t) = S_1(t)/S_1, \text{ for side 1,}$$
$$V_2(t) = S_2(t)/S_2, \text{ for side 2.} \qquad (17)$$

V_1 and V_2 are characteristics of the combat dynamics and they enable determining the mean value of the un-destroyed combat units for both sides.

It is obviously that V_1 and V_2 are decreasing – so we can obtain Diner equations:

$$dV_1/dt = - U_2 V_1 V_2 ,$$
$$dV_2/dt = - U_1 V_1 V_2 . \qquad (18)$$

After few steps – we will obtain solutions for these Diner equations:

$$V_1 = e^{U_1 t} (U_1-U_2)/ (U_1 e^{U_1 t} – U_2 e^{U_2 t})$$
$$V_2 = e^{U_2 t} (U_1-U_2)/ (U_1 e^{U_1 t} – U_2 e^{U_2 t}) \qquad (19)$$

If $U_1=U_2=U$, then solutions are: $V_1=V_2=V= 1/(1+Ut)$.

EXPERT SYSTEMS AND FUZZY REASONING

A fuzzy expert system is an expert system that uses a collection of fuzzy membership functions and rules, instead of Boolean logic, to reason about data. The rules in a fuzzy expert system are usually of a form similar to the following:

if x is low and y is high then z = medium

where *x* and *y* are input variables (names for know data values), *z* is an output variable (a name for a data value to be computed), low is a membership function (fuzzy subset) defined on *x*, high is a membership function defined on *y*, and medium is a membership function defined on *z*. The antecedent (the rule's premise) describes to what degree the rule applies, while the conclusion (the rule's consequent) assigns a membership function to each of one or more output variables. Most tools for working with fuzzy expert systems allow more than one conclusion per rule. The set of rules in a fuzzy expert system is known as the rule base or knowledge base.

The general inference process proceeds in three (or four) steps.

1. Under FUZZIFICATION, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise.

2. Under INFERENCE, the truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule. Usually only MIN or PRODUCT are used as inference rules. In MIN inference, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth (fuzzy logic AND). In PRODUCT inference, the output membership function is scaled by the rule premise's computed degree of truth.

3. Under COMPOSITION, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable. Again, usually MAX or SUM are used. In MAX composition, the combined output fuzzy subset is constructed by taking the point wise maximum over all of the fuzzy subsets assigned to variable by the inference rule (fuzzy logic OR). In SUM composition, the combined output fuzzy subset is constructed by taking the point wise sum over all of the fuzzy subsets assigned to the output variable by the inference rule.

4. Finally is the (optional) DEFUZZIFICATION, which is used when it is useful to convert the fuzzy output set to a crisp number. There are more defuzzification methods than you can shake a stick at (at least 30). Two of the more common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth-value is chosen as the crisp value for the output variable.

Assume that the variables x, y, and z all take on values in the interval $[0,10]$, and that the following membership functions and rules are defined:

$$low(t) = 1 - (t / 10); \quad high(t) = t / 10 \qquad (20)$$

rule 1: if x is low and y is low then z is high
rule 2: if x is low and y is high then z is low
rule 3: if x is high and y is low then z is low
rule 4: if x is high and y is high then z is high

Notice that instead of assigning a single value to the output variable z, each rule assigns an entire fuzzy subset (low or high).

1. In this example, $low(t)+high(t)=1.0$ for all t. This is not required, but it is fairly common.

2. The value of t at which $low(t)$ is maximum is the same as the value of t at which $high(t)$ is minimum, and vice-versa. This is also not required, but fairly common.

3. The same membership functions are used for all variables. This isn't required, and is also ‘not’ common.

In the fuzzification sub-process, the membership functions defined on the input variables are applied to their actual values, to determine the degree of truth for each rule premise. The degree of truth for a rule's premise is sometimes referred to as its *alpha*. If a rule's premise has a nonzero degree of truth (if the rule applies at all...) then the rule is said to *fire*.

In the inference sub-process, the truth-value for the premise of each rule is computed, and applied to the conclusion part of each rule. This results in one fuzzy subset to be assigned to each output variable for each rule.

MIN and PRODUCT are two *inference methods* or *inference rules*. In MIN inference, the output membership function is clipped off at a height corresponding to the rule premise's computed degree of truth. This corresponds to the traditional interpretation of the fuzzy logic AND operation. In PRODUCT inference, the output membership function is scaled by the rule premise's computed degree of truth.

The terminology used here is slightly non-standard. In most texts, the term "inference method" is used to mean the combination of the things referred to separately here as "inference" and "composition." Thus you'll see such terms as "MAX-MIN inference" and "SUM-PRODUCT inference" in the literature. They are the combination of MAX composition and MIN inference, or SUM composition and PRODUCT inference, respectively. You'll also see the reverse terms "MIN-MAX" and "PRODUCT-SUM" – these mean the same things as the reverse order. It seems clearer to describe the two processes separately. In the composition sub-process, all of the fuzzy subsets assigned to each output variable are combined together to form a single fuzzy subset for each output variable.

MAX composition and SUM composition are two *composition rules*. In MAX composition, the combined output fuzzy subset is constructed by taking the point wise maximum over all of the fuzzy subsets assigned to the output variable by the inference rule. In SUM composition, the combined output fuzzy subset is constructed by taking the point wise sum over all of the fuzzy subsets assigned to the output variable by the inference rule. Note that this can result in truth-values greater than one! For this reason, SUM composition is only used when it will be followed by a defuzzification method, such as the CENTROID method, that doesn't have a problem with this odd case. Otherwise SUM composition can be combined with normalization and is therefore a general-purpose method again.

For example, assume $x = 0.0$ and $y = 3.2$. MIN inference would assign the following four fuzzy subsets to z:

$$rule1(z) = \{ z / 10, \text{ if } z <= 6.8; \quad 0.68, \text{ if } z >= 6.8\}; \quad rule3(z) = 0.0$$
$$rule2(z) = \{ 0.32, \text{ if } z <= 6.8; \quad 1 - z / 10, \text{ if } z >= 6.8\}; \quad rule4(z) = 0.0 \qquad (21)$$

MAX composition would result in the fuzzy subset:

$$fuzzy(z) = \{ 0.32, \text{ if } z <= 3.2 ; \quad z / 10, \text{ if } 3.2 <= z <= 6.8 ; \quad 0.68, \text{ if } z >= 6.8 \} \qquad (22)$$

PRODUCT inference would assign the following four fuzzy subsets to *z*:

$$rule1(z) = 0.068 * z; rule2(z) = 0.32 - 0.032 * z; rule3(z) = 0.0; rule4(z) = 0.0 \qquad (23)$$

SUM composition would result in the fuzzy subset: $fuzzy(z) = 0.32 + 0.036 * z.$

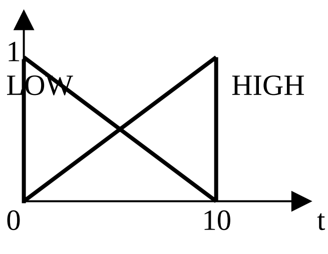

Fig. 2 – Membership functions defined above.

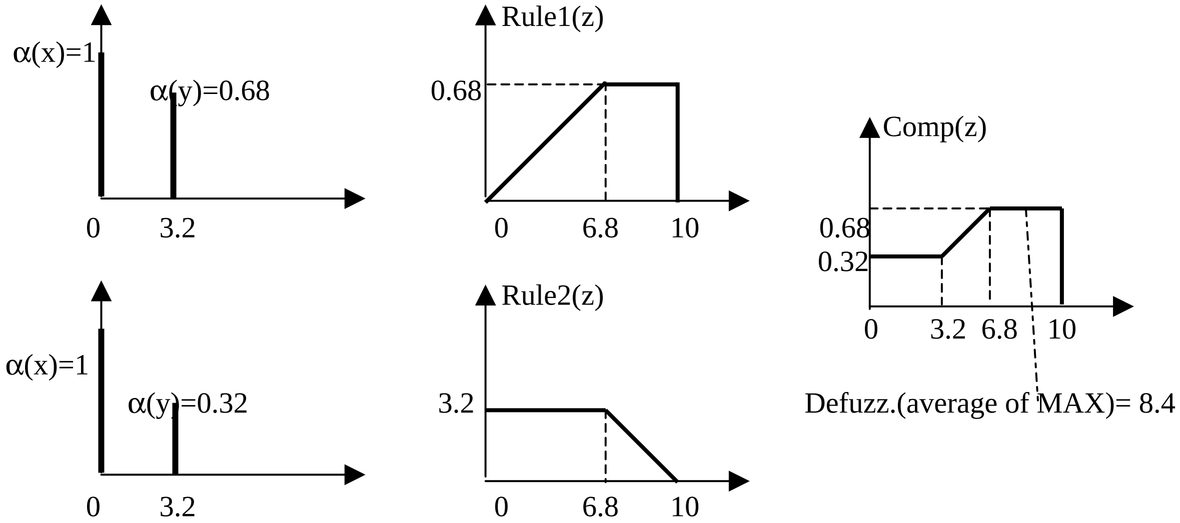

Fig. 3 – MIN inference / MAX composition for the given example.

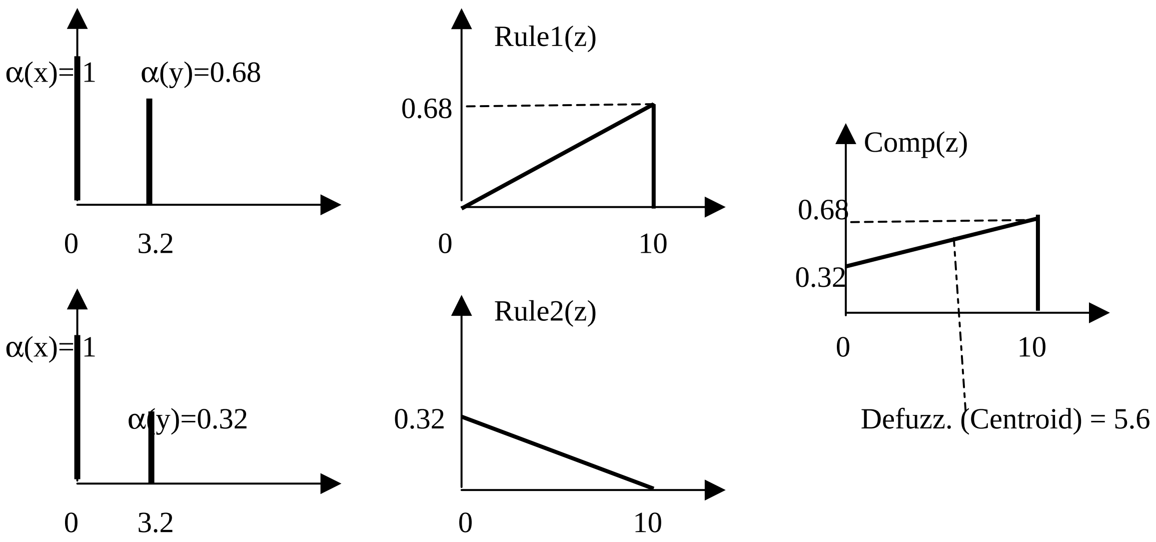

Fig. 4 – PRODUCT inference / SUM composition for the given example.

Sometimes it is useful to just examine the fuzzy subsets that are the result of the composition process, but more often, this *fuzzy value* needs to be converted to a single number - a *crisp value*. This is what the defuzzification sub-process does. There are more defuzzification methods than you can shake a stick at. A couple of years ago, Mizumoto did a short paper that compared about ten defuzzification methods. Two of the more common techniques are the CENTROID and MAXIMUM methods. In the CENTROID method, the crisp value of the output variable is computed by finding the variable value of the centre of gravity of the membership function for the fuzzy value. In the MAXIMUM method, one of the variable values at which the fuzzy subset has its maximum truth-value is chosen as the crisp value for the output variable. There are several variations of the MAXIMUM method that differ only in what they do when there is more than one variable value at which this maximum truth-value occurs. One of these, the AVERAGE-OF-MAXIMA method, returns the average of the variable values at which the maximum truth-value occurs.

For example, go back to our previous examples. Using MAX-MIN inference and AVERAGE-OF-MAXIMA defuzzification results in a crisp value of *8.4* for *z*. Using PRODUCT-SUM inference and CENTROID defuzzification results in a crisp value of *5.6* for *z*, as follows. We state that all variables (including *z*) take on values in the range *[0, 10]*. To compute the centroid of the function *f(x)*, you divide the moment of the function by the area of the function. To compute the moment of *f(x)*, you compute the integral of *x*f(x)dx*, and to compute the area of *f(x)*, you compute the integral of *f(x)dx*. In this case, we

would compute the area as integral from *0* to *10* of *(0.32+0.036*z)dz*, which is *(0.32 * 10 + 0.018*100) = (3.2 + 1.8) = 5.0*, and the moment as the integral from *0* to *10* of *(0.32*z+0.036*z*z)dz*, which is *(0.16 * 10 * 10 + 0.012 * 10 * 10 * 10) = (16 + 12) = 28*. Finally, the centroid is *28/5* or *5.6*.

Note: Sometimes the composition and defuzzification processes are combined, taking advantage of mathematical relationships that simplify the process of computing the final output variable values.

To date, fuzzy expert systems are the most common use of fuzzy logic. They are used in several wide-ranging fields, including linear and non-linear control, pattern recognition, financial Systems, operation research, data analysis etc.

MODELLING OF COMBAT ACTIONS WITH FUZZY TOOLBOX

In this chapter we will connect previous two chapters, i.e. we will define two expert systems containing different rule bases, which give an alternate solution for the amount of caused damages to the enemy, according to Lanchester and Diner equations. The advantage of an expert system in problem solution is using of natural language expressions, instead of complex mathematical models.

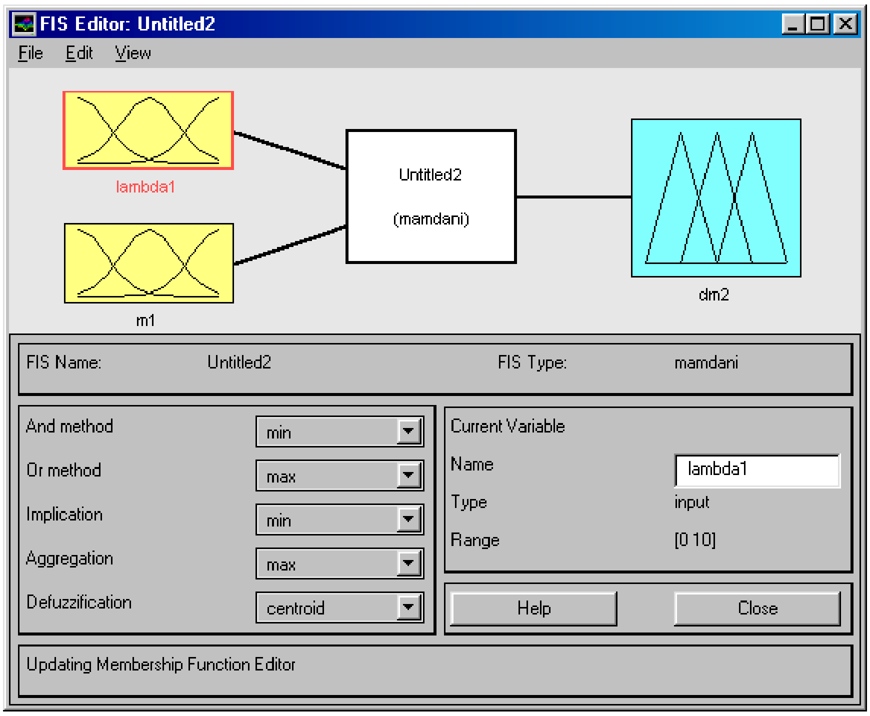

Fig. 5 – Fuzzy inference system from Fuzzy Toolbox.

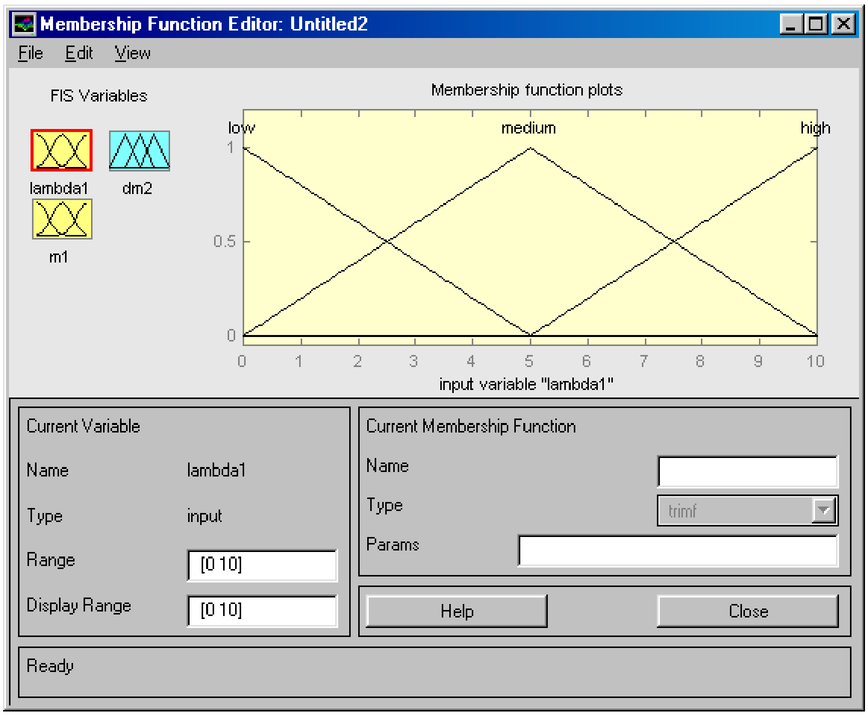

Fig. 6 – Membership function definition for the variable λ_r.

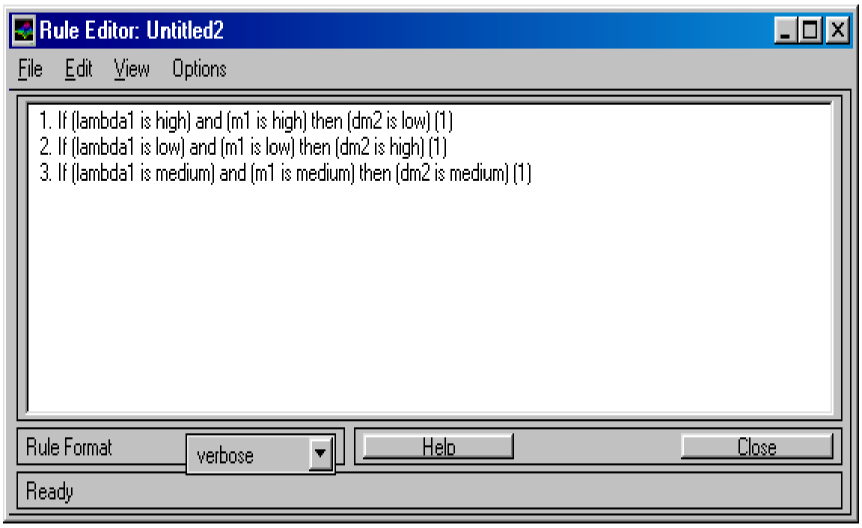

Fig. 7 – Rule editor in Fuzzy Toolbox – example for Lanchester equations.

We used Matlab's Fuzzy Toolbox and it's main component - the FIS editor that displays high-level information about a Fuzzy Inference System. At the top is a diagram of the system with each input and output clearly labelled. By double-clicking on the input or output boxes, you can bring up the Membership Function Editor. Double-clicking on the fuzzy rule box in the centre of the diagram will bring up the Rule Editor. Just below the diagram is a text field that displays the name of the current FIS. In the lower left of the window are a series of popup menus that allow you to specify the various functions used in the fuzzy implication process. In the lower right are fields that provide information about the current variable. The current variable is determined by clicking once on one of the input or output boxes.

The Membership Function (MF) Editor is used to create, remove, and modify the MFs for a given fuzzy system. On the left side of the diagram is a "variable palette" region that you use to select the current variable by clicking once on one of the displayed boxes. Information about the current variable is displayed in the text region below the palette area. To the right is a plot of all the MFs for the current variable. You can select any of these by clicking once on the line or name of the MF. Once selected, you can modify the properties of the MF using the controls in the lower right. MFs are added and removed using the Edit menu.

The Rule Editor displays the rules associated with a given fuzzy system. Rules can be edited and displayed in any of three different modes. Verbose mode use words like "if" and "then" to make the rules read as much like normal sentences as possible. Symbolic mode is a language neutral mode that relies on symbols to specify the relationship between the parts of the rule. Indexed mode is a highly abbreviated version in which each input and output variable corresponds to a column and MFs are referred to by their index number.

The Rule Viewer displays, in one screen, all parts of the fuzzy inference process from inputs to outputs. Each row of plots corresponds to one rule, and each column of plots corresponds to either an input variable (yellow, on the left) or an output variable (blue, on the right). You can change the system input either by typing a specific value into the Input window or by moving the long yellow index lines that go down each input variable's column of plots. The aggregate membership function for each output variable is shown in the bottom right along with the defuzzified output value.

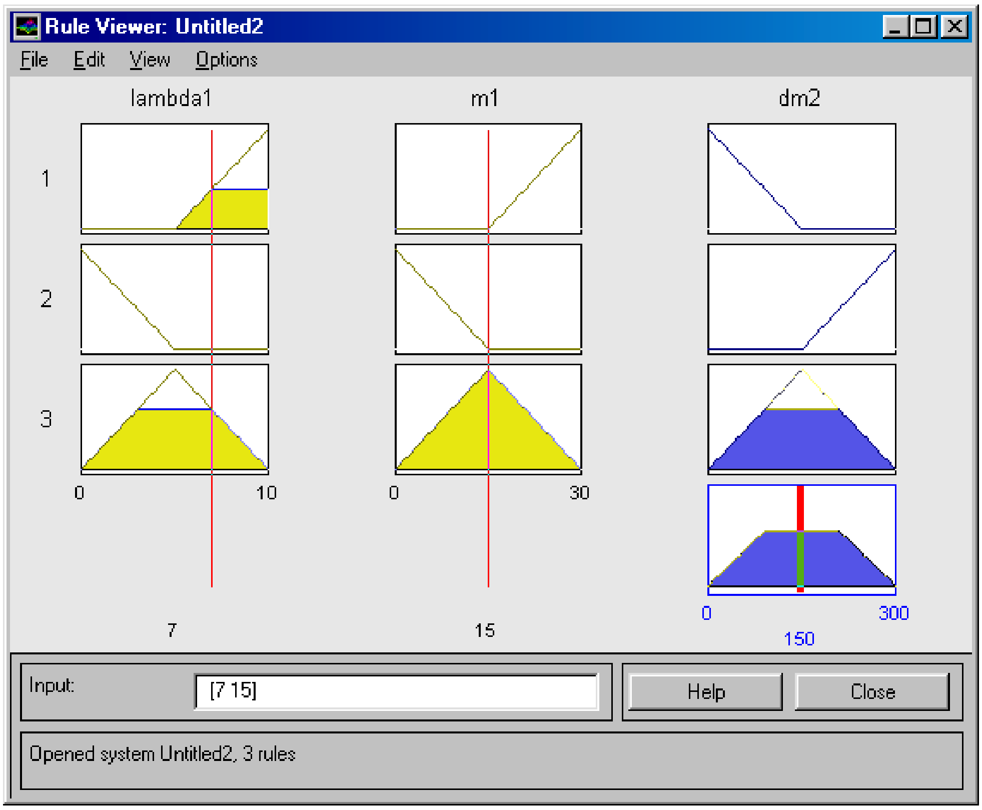

Fig. 8 – Obtained results for dm_2/dt.

We have used FIS for modelling of Lanchester and Diner equations, (12) and (16). First we modelled the decreasing of the number of our combat units dm_2/dt. We defined triangular membership functions {*low*, *medium*, *high*} for the variables with appropriate crisp sets: $\lambda_1 \in [0, 10]$, $m_1 \in [0, 30]$ and $dm_2/dt \in [0, 300]$ -see fig. 6. On fig. 7 – rule base for Lanchester equations is given, and on fig. 8 – reasoning process and obtained crisp values are given. If we put more rules in the knowledge base – the obtained results will be more accurate. For Diner equations – we modelled the enemy's initial fire power – U_1. We defined triangular membership functions {*low*, *medium*, *high*} for the variables with appropriate crisp sets: $\lambda_1 \in [0, 10]$, $p_1 \in [0, 1]$, $\sigma_1 \in [0, 10]$, $N_1 \in [0, 30]$ and $S_2 . \in [0, 500]$. Simulation results are obtained as shown on fig. 5-fig.8.

*On the battle field – instead of calculation, we can estimate: "If the enemy has a **large number** of combat units, with **high** shooting velocity, then we will lose our units **very fast**". This approach for modelling of combat actions via fuzzy rule base, can also be applied for all other cases where IF..THEN rules can be identified, instead of mathematical equations. Fuzzy logic is widely used for navigation of autonomous land vehicles, for missile guidance, for servo-control mechanism of some artillery weapon etc.*

In the last chapter of this paper – we propose an original reformulation for execution of fuzzy expert system – via fuzzified Petri net.

FUZZY-PETRI NET REASONING ALGORITHM

We will consider the most generic representation of the rules, which make up the knowledge base (KB) in a fuzzy production system (FPS):

$$R^r\text{: IF } \mathbf{X_1^r \text{ IS } A_1^r} \text{ AND ... AND } \mathbf{X_{Mr}^r \text{ IS } A_{Mr}^r} \text{ THEN}$$
$$\mathbf{X_{Mr+1}^r \text{ IS } B_1^r} \text{ AND ... AND } \mathbf{X_{Mr+Nr}^r \text{ IS } B_{Nr}^r}\text{ , } (\tau^r),$$

where the bold parts are fuzzy propositions and τ^r are linguistic values of the truth-variable which qualify the rules. We are going to approach the projection of a KB onto a Petri net (PN) and we start by identifying the places of the PN with the propositions of the KB by means of bijective function:

$$\alpha: P \text{ -> } PR,\ p_k \text{ -> } \alpha(p_k)=pr_k,\ \ k=1,...,K, \qquad (24)$$

where $PR=\{ pr_k \}$ is the set of propositions in the KB and K is the number of propositions in the KB. In the case where a proposition is found several times in different rules of the KB, a different place will be assigned to it for each of these appearances in the KB. The description of the meaning of the transitions is more complex, because of the linking rules. In our representation $T = T^R\ U\ T^C = \ = \{ t^1,...,t^R,t^{R+1},...,t^{R+C}\}$. Subset T^R includes the transitions associated with each one of the rules, which make up the KB, whereas subset T^C includes the transitions that are associated with the existence of links between propositions. We define the input and the output functions over set T - $I(t^j)$ and $O(t^j)$:

$$\text{If } t^j \in T^R,\ \forall p_i \in P,\ p_i \in I(t^j) <=> a(p_i) \in \text{Antecedent part of } R^j \qquad (25)$$
$$\text{If } t^j \in T^R,\ \forall p_i \in P,\ p_i \in O(t^j) <=> a(p_i) \in \text{Consequent part of } R^j \qquad (26)$$
$$\text{If } t^j \in T^C,\ p_i \in I(t^j)\ ,\ p_k \in O(t^j) <=> a(p_i) \text{ is linked with } \alpha(p_k) \qquad (27)$$

Therefore a single transition $t^j \in T^C$ will exist for each of the intermediate variables X_j of the KB.

The fundamental notion for execution of a KB is marked PN. Marking indicates that the degree of fulfilment (DOF) of the associated proposition is known, so this proposition can be used in the process of obtaining new references. It will be necessary for the DOF's of the different propositions to be available all the time. So we define the fulfilment function, which assigns to each place a real value:

$$g(p) = DOF(\alpha(p)) \qquad (28)$$

In our representation tokens are transferred from some places to others by means of the activation of transitions, following a basic rule: A transition $t^j \in T$ is active (and will fire) if every $p_i \in I(P)$ has a token. When during the process of firing a transition the token of the input places is removed, the information obtained about the DOF of that propositions are preserved in the fulfilment function. The firing of an active transition $t^j \in T^R$ is equivalent to the application of a rule in the process of evaluating the KB. The activation of $t^j \in T^C$ is equivalent to knowing, whether it be through previously performed inferences or through observation, the DOF of propositions $\alpha(p_i)$, $p_i \in I(t^j)$. In this case, the DOF for propositions $\alpha(p_k)$, $p_k \in O(tj)$ is determined not by the application of rules of the KB, but by essentially the same method as the one used to determine the DOF of a proposition with observed input distribution values. Most of the operations participating in this calculation can be carried out a priori, leading to a significant simplification of the execution process. When all DOF's of the antecedent part of a rule are known and it is executed, the marking function will have placed tokens in all of the input places of the corresponding transition, activating it and causing it to fire, which will produce a new marking function.

The definition of the initial marking function M in the PN representation of the KB of a FPS can be established as:

$$M : p \dashrightarrow \{ 0,1 \},\ p_i \dashrightarrow M(p_i)= \{ 0, \text{if } g(p_i) \text{ is unknown};\ 1, \text{otherwise}\} \tag{29}$$

The marking function thus makes explicit the requirement that the DOF of a set of propositions must be known before an evaluation of the KB can be carried out. From a given marking function M, the firing of a transition t^j will produce a new marking function M'. The evolution of the marking functions of a PN is described by the transition function tf:

$$tf: M \times T \dashrightarrow M,\ (M,t^j) \dashrightarrow M' \tag{30}$$

where:

$$M'(p_i)=\{ 0, \text{if } p_i \in I(t^j);\quad 1, \text{if } p_i \in O(t^j);\ M(p_i), \text{otherwise}\} \tag{31}$$

and M represents the set of all possible marking functions of the PN. In the data driven evaluation strategy, the possibility distributions associated with input variables of the KB are initially known through observation. These known distributions will allow certain rules to fire and, as a result, new possibility distributions to be assigned to other (intermediate or output) variables. Repeating the process as many times as necessary, the complete evaluation of the KB is carried out until a possibility distribution is associated to each of the output variables.

The process of executing a KB can be understood as the “propagation” of possibility distributions through the KB, via implication operations (which permit “propagating” distributions from the antecedent part of a rule to the consequent part of the same rule) and via links (which “connect” the consequent part of one or several rules to the antecedent part of other(s)). This evaluation process is carried out following a certain order, which determines at any moment in time the rule(s) that may be applied. The process finishes with the operation of aggregating all the possibility distributions inferred for each output variable into a single final possibility distribution.

Without loss of generality, we analyse a KB which consist of only two chained rules:

$$R^S\text{: IF } X1^S \text{ IS } A1^S \text{ AND ... AND } X_{Ms}{}^S \text{ IS } A_{Ms}{}^S \text{ THEN } X_{Ms+1}{}^S \text{ IS } B_1{}^S \text{ AND ...AND } X_{Ms+Ns}{}^S \text{ IS } B_{Ns}{}^S\ (\tau^S)$$
$$R^T\text{: IF } X1^T \text{ IS } A1^T \text{ AND...AND } X_{MT}{}^T \text{IS } A_{MT}{}^T \text{THEN } X_{MT+1}{}^T \text{ IS } B_1{}^T \text{AND...AND } X_{MT+NT}{}^T \text{IS } B_{NT}{}^T\ (\tau^T) \tag{32}$$

which are linked by :

$$X_{Ms+1}{}^S = X_1{}^T \tag{33}$$

In order to represent the rule pair in the formalism we have described, we must first define the bijective function α, which relates places and propositions to this end; we define the following set of places:

$$P= \{ p^r{}_{mr} \mid m_r = 1, \ldots ,Mr+Nr, r=S,T \} \tag{34}$$

and the set of propositions:

$$PR=pr^r{}_{mr} = \{ \text{"}X^r{}_{mr} \text{ IS } A^r{}_{mr}\text{"}, mr<= Mr;\ \text{"}X^r{}_{mr} \text{ IS } B^r{}_{mr-Mr}\text{"}, mr>Mr\} \tag{35}$$

Furthermore, given the simplicity of our KB, the transition for the rules and links are:

$$T^R= \{ t^S, t^T\} \tag{36}$$
$$T^C = \{ t^3 \} \tag{37}$$

The graphic representation of rules considered is shown on fig. 9:

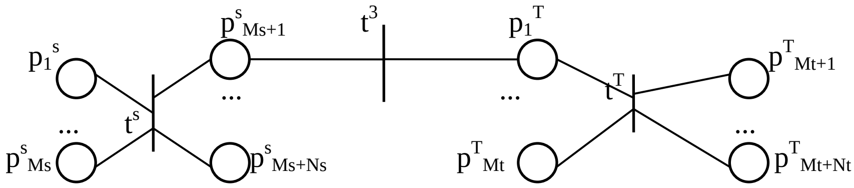

Fig.9 - Representation of the chaining of two rules in the PN formalism.

We will focus on the process of obtaining the DOF corresponding to proposition $\alpha(p_1{}^T)$ from the DOF of $\alpha(p_{Ms+1}{}^S)$, i.e. $g(p_1{}^T)$ from $g(p_{Ms+1}{}^S)$. We can write:

$$\underline{b}^S{}_{1,i} = \tau^S(g(p_{Ms+1}{}^S) \wedge b^S{}_{1,i}), \quad i=1,...,I \tag{38}$$

where $B^S{}_1 = \{ b^S{}_{1,i} \}$ is the possibility distribution associated with linguistic value $B^S{}_1$ in proposition $\alpha(p_{Ms+1}{}^S)$. The DOF will be:

$$g(p_1{}^T) = \bigvee_{i=1,I} [\tau^S(g(p_{Ms+1}{}^S) \wedge b^S{}_{1,i}) \wedge a^T{}_{1,i}] \tag{39}$$

where $a^T{}_{1,i}$ is possibility distribution of linguistic value A in propositions.

If linguistic truth variable τ^s is a monotonically increasing function:

$$g(p_1{}^T) = \tau^S(g(p_{Ms+1}{}^S)) \wedge \bigvee [\tau^S(b^S{}_{1,i}) \wedge a^T{}_{1,i}] \tag{40}$$

i.e. the DOF existing between possibility distribution $\tau^S(B_1{}^S)$ and $A_1{}^T$, whose calculation can be performed at the moment of the definition of the KB.

The algorithm will basically consist of two stages: definition of the marking function and production of the DOF's of the corresponding propositions and firing of the active transitions. These stages are sequentially repeated until there are no more active transitions; at in which time the inference process will have ended. Finally, we perform aggregation - assignment of a single possibility distribution to each output variable. Let IP and OP be the sets, which group input and output places respectively.

Step 1 Initially we assume we know only the DOF's of the propositions, which operate on input variables, that is, those associated with input places. Therefore, the initial marking function will be:

$$M(p_i) = \{ 0, \text{ if } p_i \notin IP;\ 1, \text{ if } p_i \in IP \} \tag{41}$$

Step 2 We fire the active transitions. Let t^j be any active transition; that is,

$$\exists t^j \in T \,/\, \forall p_k \in I(t^j), M(p_k)=1 \tag{42}$$

The transition function *tf*, which defines the successive marking functions will be as defined with *(29)* and *(30)*. Also, the corresponding DOF's are obtained as follows:

$$\text{If } t^j \in T^R,\ g(p_i) = \bigwedge g(p_k)\ ,\ \forall p_i \in O(t^j),\ p_k \in I(t^j) \tag{43}$$

$$\text{If } t^j \in T^C,\ g(p_i) = \bigvee [\tau^{rk}(\,g(p_k)) \wedge \mu_{pk,pi}]\ ,\ \forall p_i \in O(t^j), p_k \in I(t^j) \tag{44}$$

Step 3: Go back to step 2, while:

$$\exists t^j \in T \mid M(p_i) = 1,\ \forall p_i \in I(t^j) \tag{45}$$

Step 4: For each output variable X, its associated possibility distribution $\underline{B}=\{\underline{b}_i\}$, $i=1,...,I$, will be:

$$\underline{b}_i = \bigvee \tau^r(g(p_n^r)) \wedge \tau^r(b^r_{n,i}), \quad p_n^r \in Px \qquad (46)$$

where the set P_X of places associated with propositions in which inferences over X are carried out is defined by:

$$Px = \{ p_n^r \in P \mid \alpha(p_n^r) = \text{"}X\ IS\ Bn^r\text{"}\} \qquad (47)$$

Further we give some simulation results obtained from fuzzy-Petri net reasoning simulator, realised in Visual Basic:

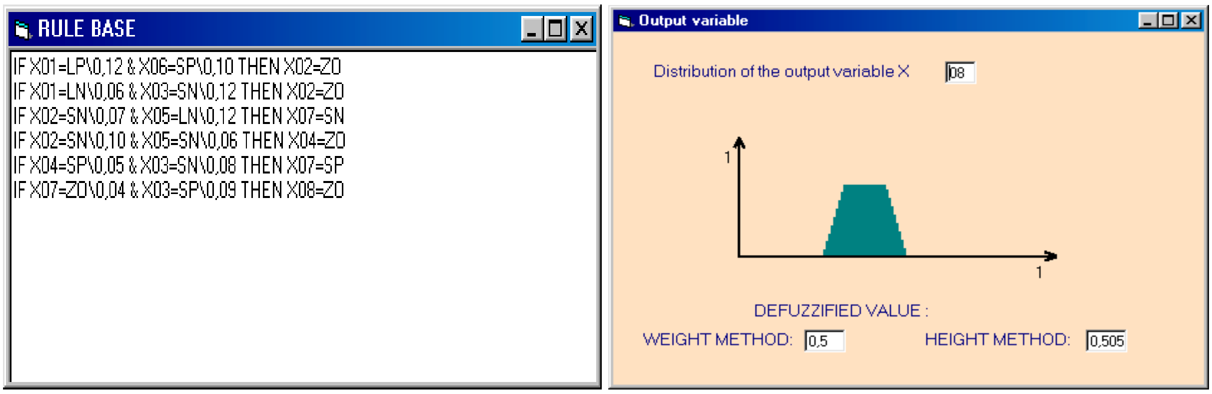

Fig.10 - Rule base and obtained output variable.

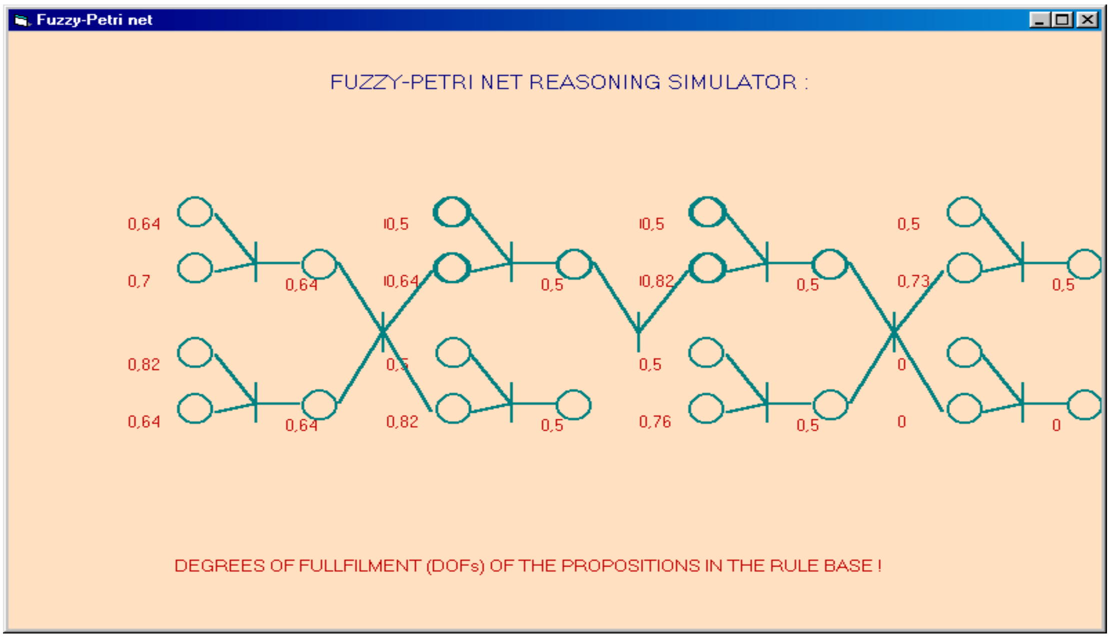

Fig.11 – Fuzzy Petri net reasoning simulator.

CONCLUSION

In this paper we described new approach for modelling of combat actions – via fuzzy expert system. We comprehended two combat actions in our paper – battle dynamics between two opposite sides with Lanchester and Dinner equations. First, we described classical mathematical models of these combat actions. After it – we have defined two expert systems containing different rule bases, which give an alternate solution for the decreasing of the number of combat units and for initial fire power. We identified fuzzy rules for these combat actions, fuzzy variables and accompanied fuzzy sets. In the second part of the paper – we focused on evaluation of the rules from the fuzzy knowledge bases, and obtaining of appropriate output

variable possibility distribution, as well as it's defuzzified (crisp) value. We showed some simulation results obtained by Matlab's Fuzzy Toolbox, and compared them with the classical mathematical models of these two combat actions. In the last section of this paper – we gave an overview of a reasoning expert system we have developed and implemented in Visual Basic. It is based on fuzzified Petri nets, with rule-based decision-making and appropriate knowledge base (KB). This development of our own reasoning system - is main contribution of this paper. The advantage of an expert system in problem solution is using of natural language expressions, instead of complex mathematical models.

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A Tactical Planning Approach by Using Artificial Intelligence Procedures

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Foreword

It is a pleasure for me to introduce the work done by Maj. Castillo and Prof. Arriaga which is related to one of the more innovative tendencies in simulation; I am referring to Intelligent Simulation. This new challenge consists of making simulation more efficient by introducing Artificial Intelligence procedures in the simulation process; what will permit to implement certain reasoning rules similar to the human reasoning process.

Spain is for the latest technologies and their applications within the simulation field, and from my post I'm decided to support any initiative that can accomplish the goal of making our Military Forces more efficient through new technologies.

The work has been developed within a spontaneous collaboration between the "Universidad Politécnica de Madrid" and the "Escuela de Informática del Ejército", with no cost and with the only idea of serving as a workbench of new technologies within the military decision support and planning.

With no doubt, this kind of collaborations will be the seed for future R&D programs.

This paper will open new expectations for those who are eager to find a technological solution in military planning.

I am sure that this Spanish contribution will satisfy the aim planned by the NMSG for the 'Future modelling and simulation challenges' Symposium.

MINISTERIO DE DEFENSA
EL DIRECTOR GENERAL DE ARMAMENTO Y MATERIAL

Gen. Carlos Villar Turrau

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

Abstract

Within the tactical manoeuvre it is vital that there be an Artillery support that allows the advancement of a Brigade, either in an offensive action or in a defensive one. An offensive action tries to break the enemy defensive position. The artillery preparation plan is the key to neutralizing the enemy defensive positions giving our infantry units the opportunity to accomplish their mission. A defensive action tries to obstruct the enemy's initiative. The artillery counterpreparation plan is in this case the key to avoiding the enemy's action.

The artillery planning begins with a list of targets, which has been acquired by the tactical acquisition echelon. The targets on the list are classified to be fired on in different phases. All of these phases are related to the different actions that our tactical units carry out and the possible enemy reactions in order to thwart our advancement, in case of an offensive manoeuvre; and vice versa in case of a defensive manoeuvre. After this classification, it is essential to distribute the scarce means of fire that a unit such as a Division or a Brigade has under its command. In this distribution it is necessary to seek a balanced solution that permits the preparation plan to be developed successfully by saving some Artillery Units that surely we must use in simultaneous and unexpected actions.

A computer aided plan would support the Artillery Command Post by proposing a faster and probably better solution than the manual human calculated one. On the other hand, it will be feasible to redistribute the targets and the artillery units in little time if the action diverges from the original plan.

This paper provides a solution by dividing each artillery plan into two problems: classification of targets, and distribution of targets among artillery units.

The Agents Theory has been used to obtain a conceptual model to reach the solution. In order to obtain a targets classification into different phases to be fired on, a classifier agent has been built by using a neural network, namely a Multilayer Perceptron which uses the backpropagation algorithm. Different training patterns are used depending on the preparation or counterpreparation artillery plan.

Once the targets are classified we resolve the targets distribution by means of the Assigner Agent; in this case we use an intelligent search that starts employing a minimum number of artillery units and goes on adding more units until a solution is reached.

A heuristic algorithm is used in order to reduce the exhaustive search.

Keywords: Planning, Preparation, Counterpreparation, Agents, Neural networks, Intelligent searches, Heuristic algorithms.

Overview

The aim of this paper is to present the result of the research work that allows the mechanization of the reasoning process in field Artillery planning by using Artificial Intelligence (AI) procedures.

The research is focused in particular on the preparation and counterpreparation artillery plans, due to their special complexity. The rest of the different artillery plans could be solved by using similar tools, perhaps in an easier way.

In this kind of problems the combinatory explosion is the factor that prevents man to prospect the whole possibilities set in real time. He only can obtain a possible solution without being certain that it is the best. For that reason, the Artificial Intelligent procedures and their implementation in high-performance computers are adapted to serve as a powerful tool in the planning process.

To serve as an example, we can imagine an artillery preparation plan for neutralizing twenty targets with five field artillery units in a ten-minutes plan. The officer in charge of the planning process will take about thirty minutes to find a viable solution, which will not be optimized by respecting a minimum use of resources, and will not be free of possible human error. By using the computer aided planning tool, the computer explores nearly a hundred and thirty five thousand possible assignation states, and it yields the solution that best fits the porpoise of the plan by saving as many artillery units as possible and taking only a few seconds.

The conceptual model to solve the problem is built on base of the Agents theory. To implement the different agents we have used Artificial Intelligence techniques such as neural networks, namely the multilayer perceptron, and intelligent searches assisted by heuristics algorithms. First we use a multilayer perceptron to classify targets in phases within the plan, and then we implement an intelligent search algorithm to make the assignation process of targets on artillery units.

The procedures used in this investigation work could be applicable to any project related to the field artillery planning process.

As a future project, and within the same investigation line, we are studying the applicability of the same conceptual tools in other different application contexts. For example, the planning process in computer science projects, or simply projects in general; in which several solutions can be reached depending on the user requirements like the minimum cost, the minimum time to finish the project or simply the minimum use of resources.

Field Artillery planning: Preparation and counterpreparation

Current situation in Artillery planning

In a very high percentage of cases, human personnel carry out the procedures used in decision support related to tactical planning in field Artillery operations. There are R&D projects that intend to integrate data communication systems that permit to transmit tactical information in real time. Then, the tactical information will be treated in a Command and Control system. However, nowadays none of these projects integrates a computer aided support related to assigning artillery units to different actions to be carried out.

Today, the current planning is made to be maintained in a long term. It’s supposed that no changes will appear. In case of any unexpected event, the human element will determine the modifications to be introduced in the plan. This is a risky factor due to the lack of time normally available in this kind of operations.

Nowadays, the necessity to make long term plans to analyze possibilities it’s a fact but always supported by the capability of reorganization in real time if an unexpected factor modifies our previous plan. This new point of view concerning planning is what we are going to call “Planning with computer aided control”.

TACTICAL PLANNING: CURRENT LIMITATIONS

The adequate application of firing means with accurate precision and in the correct moment depends, in general, on four different factors:

- Obtaining, elaborating and transmitting the tactical information
- Tactical planning
- Logistics preparation by accumulating the necessary ammunition
- Accurate execution of the planned mission

This paper focuses its attention on the planning factor with the goal of reducing the time used in making field artillery plans. We suppose that we have obtained the information about artillery targets in real time.

It’s vital that we don’t forget that even though we improve our way of making artillery plans, we won’t succeed if any of the other factors fail. A lack of coordination in the ammunition supply service or a low training level in the firing echelon would prevent carrying out the artillery plan successfully.

Within the current artillery planning system, and also extended to other planning processes, we can observe some limitations that avoid assuring the operation's complete success, due to the following factors:

- A long time is spent to make a plan, since the process is manual.
- The methods used in planning are complex, and they are sometimes applied under subjective criteria.

- The available time to make a plan is most times short. This circumstance can imply a non debugged elaboration of the plan.
- The optimization of these plans is light or simply doesn't exist. Due to the scarce available time, it is considered that the plan is well done if it follows the making rules.

PREPARATION PLAN

This kind of artillery plan is made under a specific tactical scenario. Our military units, such as Division or Brigade, are advancing and the enemy is settled in a defensive position. For our infantry units it is impossible or it implies a high cost to trespass the enemy's defensive line (FEBA -Forward Edge of the Battle Area-). An artillery operation is needed in order to neutralise the defensive enemy positions. This artillery operation must be prepared carefully with the intention to break the specific enemy's defensive positions within a time that is limited, and which mainly depends on the movement speed of our infantry units. This plan must permit our first line units to arrive to the FEBA in a particular time with a minimum of resistance. To make the preparation plan it will be needed to classify the different enemy units, in order to know which of them must be hit first.

COUNTERPREPARATION PLAN

This kind of artillery plan is made under a specific tactical scenario, just in the opposite sense of the preparation plan. Our military units, such as Division or Brigade, are settled in a defensive position. The enemy units are advancing over our defensive positions. An artillery operation is needed in order to neutralise the enemy attack, especially before it can carry out an artillery preparation plan. This artillery operation must be prepared carefully with the intention to combat the specific enemy's units within a time that is limited. This plan must permit the neutralisation of the enemy's offensive operation, and it will allow our units to reorganise themselves and to change the tactical scenario with the possibility to start an offensive operation.

Conceptual Tools: Stimulus/Response agents

An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through effectors. An agent's behavior depends only on its percept sequence to date, then we can describe any particular agent by making a table of the action it takes in response to each possible percept sequence.

Before we design an agent program, we must have pretty good idea of the possible percepts actions, what goals our performance measure that the agent is supposed to achieve, and what sort of environment it will operate in.

From a conceptual point of view, this planning process model can be built on base of two agents: one in charge of the classification process and the other responsible for the assigning process. Each of these two agents is based on a specific AI technique; in our case the classifier agent is built by using neural networks and the assigner agent has been built by means of intelligent search algorithms.

Classifier agent: Multilayer Perceptron

Typically, the network consists of a set of sensory units (source nodes) that constitute the input layer, one or more hidden layers of computation nodes, and an output layer of computation nodes. The input signal propagates through the network in a forward direction, on a layer-by-layer basis. These neural networks are commonly referred to as multilayer perceptrons (MLPs), which represent a generalization of the single-layer perceptron.

Multilayer perceptrons have been applied successfully to solve some difficult and diverse problems by training them in a supervised manner with a highly popular algorithm known as the error back-propagation algorithm. This algorithm is based on the error-correction learning rule. As such, it may be viewed as a generalization of an equally popular adaptive filtering algorithm: the ubiquitous least-mean-square (LMS) algorithm.

Basically, error back-propagation learning consists of two passes through the different layers of the network: a forward pass and a backward pass. In the forward pass, and activity pattern (input vector) is applied to the sensory nodes of the network, and its effect propagates through the network layer by layer. Finally, a set of outputs is produced as the actual response of the network. During the forward pass the synaptic weights of the networks are all fixed. During the backward pass, on the other hand, the synaptic weights are all adjusted in accord with an error-correction rule. Specifically, the actual response of the network is subtracted from a desired target to produce an error signal. This error signal is then propagated backward through the network, against the direction of synaptic connections -hence the name “error back-propagation.” The synaptic weights are adjusted to make the actual response of the network move closer to the desired response in a statistical sense. The error back-propagation algorithm is also referred to in the literature as the back-propagation algorithm. The learning process performed with the algorithm is called back-propagation learning.

A multilayer perceptron has three distinctive characteristics:

- The model of each neuron in the network includes a nonlinear activation function. The important point to emphasize here is that the nonlinearity is smooth (i.e., differenciable every where), as opposed to the hard limiting used in Rosenblatt’s perceptrons. A commonly used form of nonlinearity that satisfies this requirement is a sigmoidal nonlinearity function.
- The network contains one or more layers of hidden neurons that are not part of the input or output of the network. These hidden neurons enable the network to learn complete tasks by progressively extracting more meaningful features from the input patterns (vectors).
- The network exhibits a high degree of connectivity, determined by the synapses of the network. A change in the connectivity of the network requires a change in the population of synaptic connections or their weights.

It this through the combination of these characteristics together with the ability to learn from experiences through training that the multilayer perceptron derives it computing power.

The usage of the term “back-propagation” appears to have evolved after 1985, when its use was popularized through the publication of the seminal book entitled Parallel Distributed Processing (Rumelhart and McCelland, 1986).

The development of the back-propagation algorithm represents a landmark in neutral networks in that it provides a computationally efficient method for the training of multilayer perceptrons.

Assigner agent: Intelligent Searches

Despite its intuitive aspect, man has needed centuries to realize that the solution to many problems in his real life is only reachable by tenting or by searching, trying to find a way to get the solution. One of the most interesting procedures in this field is the method known as the "space state method". This method has been so well accepted by the scientific community that it is nowadays one of the Problem Solving Methods (PSM). Although, this doesn't mean that it serves to solve any kind of problem, it really serves to solve problems in many fields such as engineering, economics and even in games.

The application of the method requires that the system or process we are going to model permits the representation of a succession of different situations that are called "system states", which are characterized by a variable set that forms the state vector.

The space state method appears within the Dynamics of Systems. In our case in particular, the variables that conform the state of the system are usually qualitative and the state number is finite. The possible state set is known as the space of state.

The state that corresponds to the initial momentum is called the initial state, and the last state that corresponds to the end of the process is called the final state. These special states are normally known, and it is possible to have several states to start or end a process.

Within this method, the operators are the principal elements. We understand as operator, the action or actions that acting on a particular system's state produces a new state different from the previous one.

In many cases the operators are the resources that belong to the system and we can chose them without any restriction. Consequently, an operator is a function characterized by its intensity, the state vector and other variables such as the time.

Not all operators must be available to act at any moment. Each operator can have associated a series of conditions that must be accomplished before it could be applied. Due to this last circumstance, it's possible that a node has no descendent nodes; however, this last node in the branch may not be the solution to our problem.

We can assume that a system could be defined within the space state method, when we can obtain the state vector, the possible system's states (initial and final included), and the available operators set. Our problem now will be how to determine the operators' sequence to be applied in our system in order to obtain the path from the initial to the final state.

Initially the operators' sequence and its corresponding searching path may or may not exist. In the case that this path exists, it is possible that it is single or multiple; in this last case we should plan to look for the best seeking path according to a minimum cost or time criterium, a maximum benefit criterium, etc.

Implemented solution

The intelligent plans maker has been modeled as an agents-based system, in which we have developed two different agents with capability to perceive and treat information in order to perform the consequent reaction. In our case, the reactions will consist of a list of classified targets or an optimized plan, depending on the agent.

The basic elements of each agent are shown in the following table:

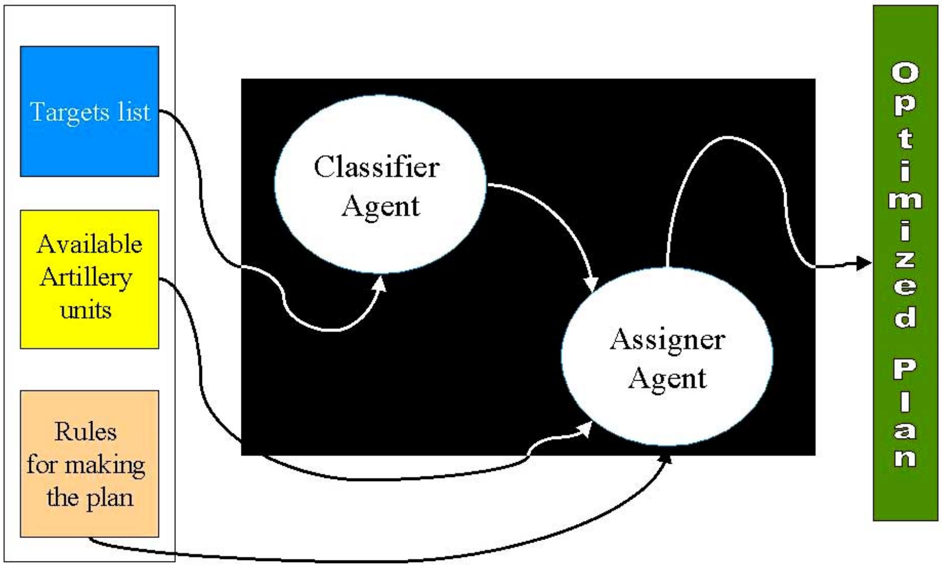
Agent Type	Percepts	Actions	Goals	Environment
Targets Classifier	A list of possible targets	detecting target type, checking distance to FEBA	A classified targets list	A file stored in a hard disk, or a table in memory
Targets Distributor	A list of classified targets	detecting plan's variables, applying making rules and operators	An optimized plan	Files stored in a hard disk, or tables in memory

From a user's point of view the computerized planning system works as a black box to which it's necessary to give some inputs and it will yield the possible solution to the problem.

In our case, the inputs will contain information about three different aspects:

- Targets to hit
- Available Artillery units
- Making rules to build the plan

On the other hand, the system will give us an output, which will consist of a tactical artillery plan.



Taking a look at the black box; we can observe the clear function of the two agents. The first one, that we can call ‘the targets classifier’ is in charge of the classification of the targets in different phases; the different targets are separated according to their internal and external characteristics. The second agent, that we can call ‘the targets assigner’ is in charge of assigning the classified targets to the field artillery units that are available to accomplish the plan.

The targets classifier agent

Depending on the selected plan; the targets contained on the list, filled out by the corresponding FSE, have to be classified in three or two phases, in case of preparation or counterpreparation plan. The targets classification agent is responsible for making the classification process. This agent is based on an AI procedure such as the neural networks. We use a Neural Network as a tool to classify the targets. In order to define the different patterns that serve as inputs of the Neural Network, an exhaustive analysis about the target’s attributes has to be made. The neural network’s output will determine the plan phase in which the target has to be included.

With the analysis of target’s attributes, we try to simplify the subjectivity of the human reasoning process. Once we have obtained the target’s attributes, we match them with the correspondent phase in which the target must be included. This information has been provided by a human expert team. The neural network is ready to be trained, and it will yield the classification process automatically.

INPUT PATTERNS IN THE NEURAL NETWORK

Once we have studied the characteristics of the targets, we extract those that will be the object of the neural network training. These characteristics are:

- Type or subtype of target
- Proximity to the FEBA (Forward Edge of the Battle Area)

For the Neural Network training phase, twenty eight different target subtypes have been codified in a binary mode, by using five inputs with possible values 0 or 1. The proximity to the FEBA has been codified with real values in a margin between 0 to 0.12. In this way we express the distance of the target to the FEBA in kilometres divided into 100. Thus, we get a shorter training phase of the neural network since we use pattern values in a very narrow margin.

OUTPUT PATTERNS OF THE NEURAL NETWORK

The preparation and counterpreparation field artillery plans need a previous target classification in Phase I, II or III and Phase I or II respectively. We need another output to define those targets located in an

excessive distance to the FEBA; it is no use including them in the plan, for this reason we introduce the output 0 that indicates that this target is rejected from the classification process.

The neural network output has been codified according to the following table:

Phase	Binary codification
I	0 1
II	1 0
III	1 1
rejected target	0 0

The codified output 1 1 has no sense when processing a target classification related to a field artillery counterpreparation plan.

THE NEURAL NETWORK TRAINING PHASE

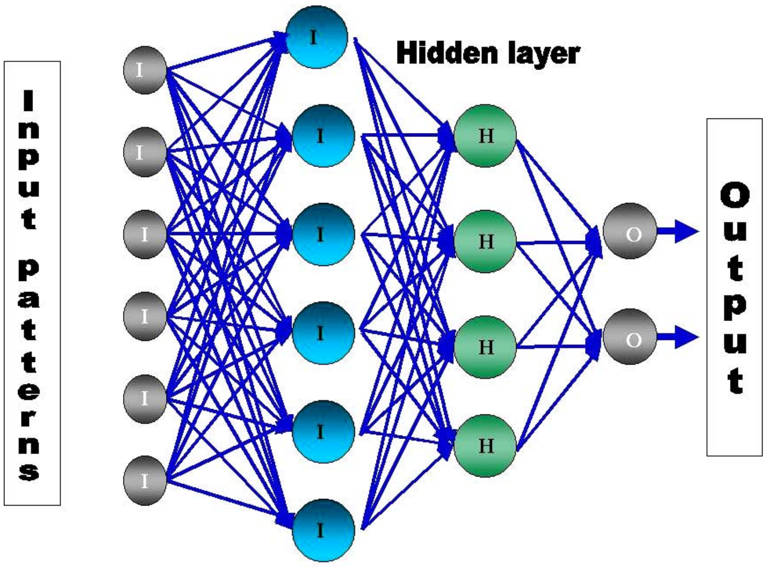
The different training patterns to train the neural network have been obtained from the experience of an expert group in artillery planning.

In the following table the non-codified training input and output patterns are shown. For simplicity, we have included in the following table the training outputs for a preparation and counterpreparation plan. Evidently, we train two different neural networks, one for each type of plan.

The following data are shown in every line of the table: the target type, the distance to the FEBA and the phase in which the target should be included depending on the field artillery plan.

Categ.	Type	Proximity	Preparation	Counterprep.
1	Artillery Units (>=155)	0	I	I
		0,06	I	I
		0,07	I	0
		0,12	I	0
	Artillery Units (<155)	0	I	I
		0,06	I	I
		0,07	I	0
		0,12	I	0
2	Mortar Units (>=90)	0	I	I
		0,06	I	I
		0,07	0	0
		0,12	0	0
	Mortar Units (<90)	0	I	I
		0,04	I	I
		0,05	0	0
		0,12	0	0
3	Launcher Rockets Units	0	I	I
		0,06	I	I
		0,07	I	0
		0,12	I	0
	Missile Units	0	III	I
		0,04	III	I
		0,05	0	0
		0,12	0	0
4	Fire support PC,s	0	I	I
		0,12	I	I
	Fire support observatories	0	I	I
		0,12	I	I

5	Radar	0	I	I
		0,12	I	I
	Passive acquisition means	0	I	I
		0,12	I	I
6	NBQ units	0	I	I
		0,06	I	I
		0,07	I	0
		0,12	I	0
7	AA PC,s	0	0	0
		0,12	0	0
	AA Radar	0	0	0
		0,12	0	0
	AA. Cannon units	0	0	0
		0,12	0	0
	AA low altitude missile units	0	0	0
		0,12	0	0
	AA medium alt. missile units	0	0	0
		0,12	0	0
	AA high altitude missile units	0	0	0
		0,12	0	0
8	PC,s and transmissions centres	0	II	II
		0,12	II	II
	Task units	0	III	I
		0,06	III	I
		0,07	0	0
		0,12	0	0
	RECO and TOPO elements	0	II	II
		0,06	II	II
		0,07	0	0
		0,12	0	0
	EW units	0	II	II
		0,12	II	II
	Engineering units	0	III	I
		0,06	III	I
		0,07	0	0
		0,12	0	0
	Supplies (fuel)	0	II	II
		0,12	II	II
	Supplies (ammunition)	0	II	II
		0,12	II	II
	Maintenance Units	0	II	II
		0,12	II	II
	Transport means	0	II	II
		0,12	II	II
	Communication lines	0	0	0
		0,12	0	0
	Other targets	0	0	0
		0,12	0	0



We have obtained experimentally the topology that permits the training of the neural network with a minimum of neurons. That topology consists of an input layer composed of six (6) neurons, a hidden layer composed of four (4) neurons and an output layer composed of two (2) neurons.

Once the network topology has been determined, we train the neural network by using the backpropagation algorithm. This algorithm fits the different neurons' input weights after each execution, until the output patterns coincide with the desired patterns.

After the training phase, we proceed to check that the neural network is able to extrapolate coherent answers when we present different patterns from the training patterns set.

For example, we trained the neural network with a pattern that defines an antitank missile unit located 2 Km from the FEBA to obtain an output that classifies this target to be included in phase III. When we introduce the same target in the network, but this time located at 2,650 m. (datum not trained), the answer will still be the same. However, if the distance changes to 7,800 m. (datum not trained) the answer will be that the target shouldn't be included in the plan.

We have successfully used the same topology to solve the classification problem within a counterpreparation artillery plan, but obtaining different weights and biases.

In the following columns, the weights and biases obtained for each kind of plan after the training phase are shown.

Biases: input layer

-5.1733
-0.7952
-1.5570
-1.2092
0.1600
3.9157

Biases: hidden layer

-4.1106
-6.9188
5.0198
6.2330

Biases: output layer

2.4714
0.5208

Weights: input layer

2.9237	-3.7685	-0.9699	4.5998	0.0703	9.5347
-3.0380	-0.1416	6.8170	4.0871	-2.1463	-6.2326
6.2430	-0.4702	-1.9894	-3.8340	0.1404	-3.2211
0.9111	5.9933	1.3985	-4.9246	2.0840	-6.1106
-3.1253	4.9126	-3.2671	2.4002	0.8352	-4.9589
-0.2417	8.1634	-4.8478	-3.0619	1.6690	-17.0422

Weights: hidden layer

2.8254	3.1264	1.5075	2.0507	2.7049	-5.3782
5.4608	11.3603	5.6635	0.7725	-6.3140	8.6803
9.4084	3.3867	2.8681	5.5804	-3.6459	5.6240
-1.6397	1.7583	-2.5963	-1.2041	-0.0099	-1.8075

Weights: output layer

-0.0150	0.5473	-0.0124	-1.9605
-0.5368	0.5087	-0.5115	-0.0528

Preparation plan: weights and biases

Biases: input layer

-5.3848
2.9403
11.1060
3.8676
-0.7461
3.3875

Biases: hidden layer

4.4515
-4.3669
-2.4126
1.2105

Biases: output layer

0.0873
-0.2132

Weights: input layer

2.0718	0.4186	2.0470	-1.5407	0.4542	1.0038
-4.1809	-1.2095	6.5129	6.8838	-2.2898	3.2627
-3.6876	-4.9282	-8.6697	-2.5909	1.3772	6.5206
-3.1334	-4.0660	4.4071	1.9196	-3.1050	8.6853
5.6608	-2.6114	0.0477	-5.5741	0.3332	15.4383
3.8672	-0.0029	5.1444	-2.1122	-0.4264	-20.5073

Weights: hidden layer

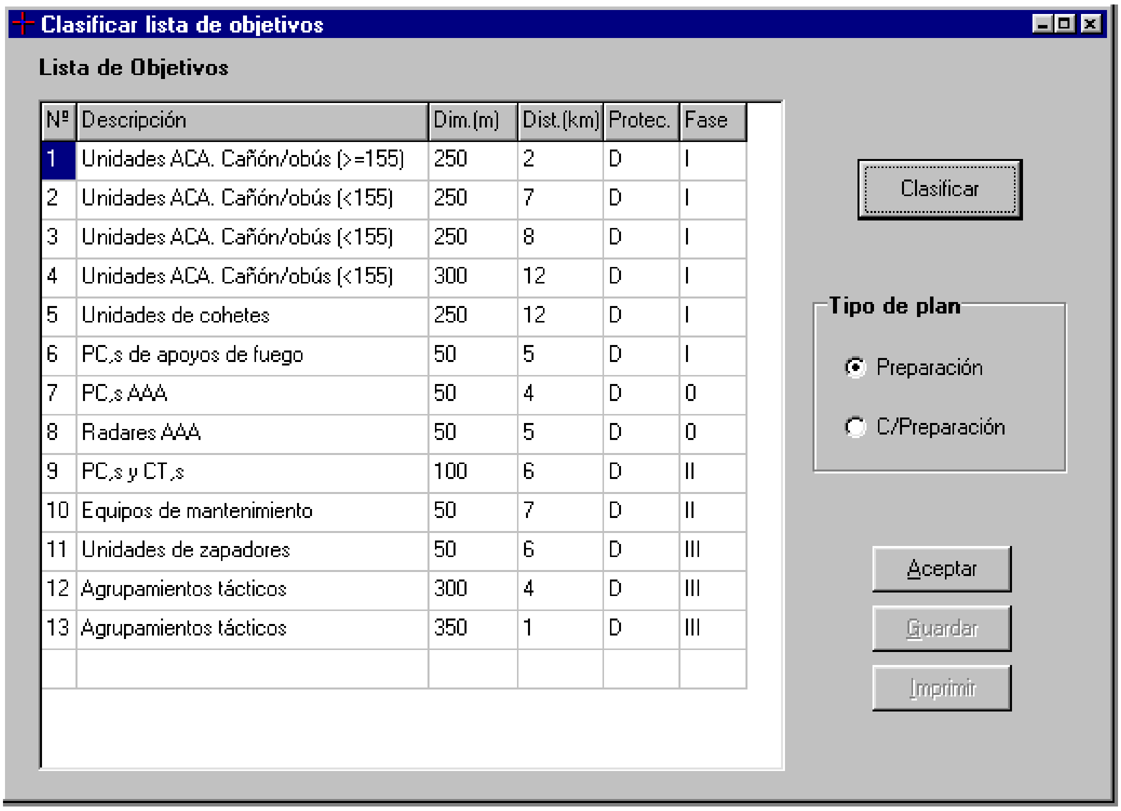
-3.6468	0.2899	-4.5591	-2.9248	-3.6039	-1.3980
4.0807	-10.5693	7.1977	5.0444	-7.3264	8.6187
2.3308	-0.4787	3.4734	0.4732	0.6909	0.5418
1.1832	-3.9779	1.7139	1.2180	-6.7649	-0.016

Weights: output layer

0.5573	-0.0047	0.1477	-0.5004
-0.4102	0.5291	-1.1630	-0.0001

Counterpreparation plan: weights and biases

From the user's point of view the classification process will consist of an interface with a list of targets, and the possibility to select the type of classification. By pushing the corresponding button the phase in which the target should be included is automatically shown.



Nº	Descripción	Dim.(m)	Dist.(km)	Protec.	Fase
1	Unidades ACA. Cañón/obús (>=155)	250	2	D	I
2	Unidades ACA. Cañón/obús (<155)	250	7	D	I
3	Unidades ACA. Cañón/obús (<155)	250	8	D	I
4	Unidades ACA. Cañón/obús (<155)	300	12	D	I
5	Unidades de cohetes	250	12	D	I
6	PC,s de apoyos de fuego	50	5	D	I
7	PC,s AAA	50	4	D	0
8	Radares AAA	50	5	D	0
9	PC,s y CT,s	100	6	D	II
10	Equipos de mantenimiento	50	7	D	II
11	Unidades de zapadores	50	6	D	III
12	Agrupamientos tácticos	300	4	D	III
13	Agrupamientos tácticos	350	1	D	III

The targets assigner agent

Once we have obtained a list of classified targets, our second goal is to solve the distribution problem. This problem consists of the correct selection of an available artillery unit to fire on a target. However not all possible assignments fit with the necessary duration of the plan. This problem is solved by the assigner agent, which is based on an Artificial Intelligence procedure, such as the intelligent search.

Due to the need of getting an optimized artillery plan that uses a minimum of artillery units, and the need of obtaining the plan in real time, we have implemented a heuristic algorithm that makes the intelligent search process shorter.

We start by studying the global factors that have influence on the assignment problem. Once we have analyzed these factors, we proceed to divide them into two groups, those that will directly affect in the search algorithm and those that will only be conditions or production rules in our software with no influence in the search process.

The following list shows the factors that are related to the assignment process and the duration of the artillery plan:

- Duration of the plan
- Programming rules
- Available Artillery units
- Artillery units caliber
- Targets to fire on
- Targets' dimensions
- Effects to produce
- Targets protection degree

From these global factors we extract those that will be used for the operators' definition, which will be applied in the search process. These factors are:

- Available Artillery units
- Artillery units caliber
- Targets to fire on
- Targets' dimensions
- Targets protection degree

We can group these factors in two groups, so the variables that will intervene directly in the operator selection process within the search algorithm will be:

Available Artillery units

- Artillery units caliber
- Effects to produce

Targets to fire on

- Targets dimensions
- Target protection degree

On the other hand, we have to elaborate the remaining factors as variables within the production rules in our software code in order to get a plan that fits the orders extracted from the Brigade or Division Master Plan. These variables are:

- Plan duration
- Specific programming rules

The duration of a particular artillery fire action will depend on the type of unit (Battery or Battalion), the materiel caliber, the effects to obtain, the target dimension and its protection degree. The relationship among all those variables will yield the necessary number of rounds. Consequently, and since the cadence is a constant datum for an artillery materiel in particular, we can calculate the duration of the artillery fire action.

SEARCH OPERATORS

The goal to be achieved when making an artillery preparation or counterpreparation plan is to hit all the selected targets within a prefixed time, by using as few artillery units as possible. To start the intelligent search we assume that the effect to produce is a constant datum for all the targets included in the list.

In our application, the following factors will be input variables dependent on the tactical situation and introduced by the user:

- Duration of the plan
- Number of targets to hit
- Targets dimensions
- Target protection degree
- Available Artillery units
- Type of Artillery units (Battery/Battalion)
- Artillery units caliber
- Effects to produce

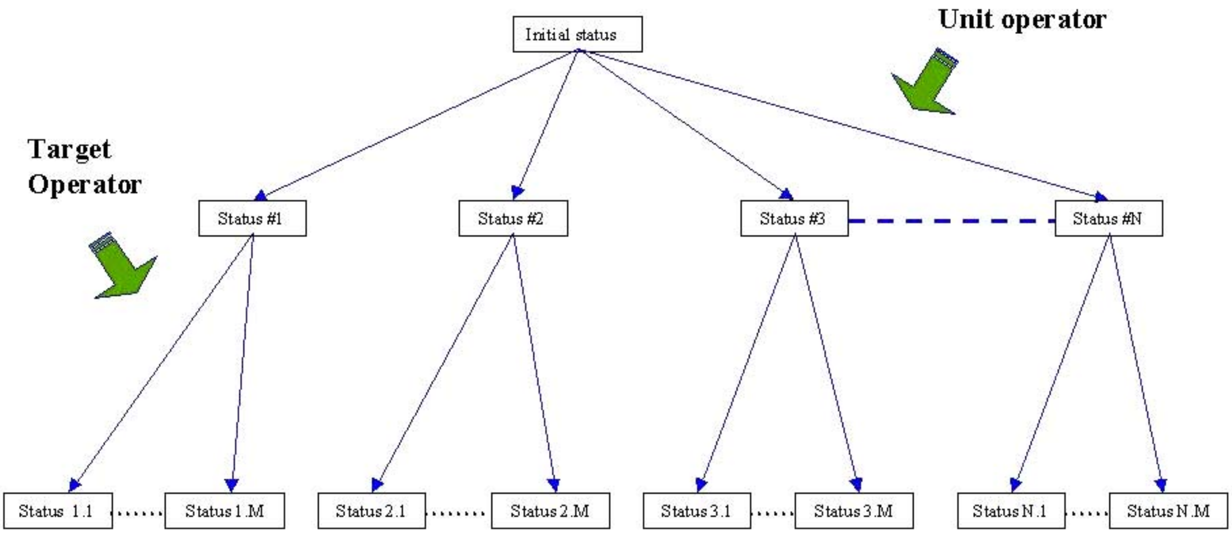
Having introduced these initial data and taking into account the duration of each individual firing action, we start the intelligent search by seeking the state that satisfies hitting all targets within the marked time by using as few artillery units as possible.

To establish the exhaustive search we define two operators:

- The unit operator
- The target operator

The unit operator is in charge of making all possible units combinations, from a single artillery unit to hit the complete target list, to all the available units.

For each of the possible combinations we need to establish the possible targets assignation. The target operator will be responsible for seeking all possibilities.



The search key consists of starting with a minimum of artillery units combining the targets set; if no solution is reached we increase a single new unit, and so on until obtaining a plan that includes all targets in the list by fitting the effects and time requirements.

If the exhaustive search arrives to the last state by using all artillery units and the possible targets combinations and no solution is found, the possibilities are either to increase the number of artillery units available or to reduce the target list.

The complexity of the exhaustive searches lies in the very high number of states produced in the seeking process. For instance, an artillery preparation plan with five artillery units and twenty targets to hit produces nearly a hundred and thirty five thousand possible combinations.

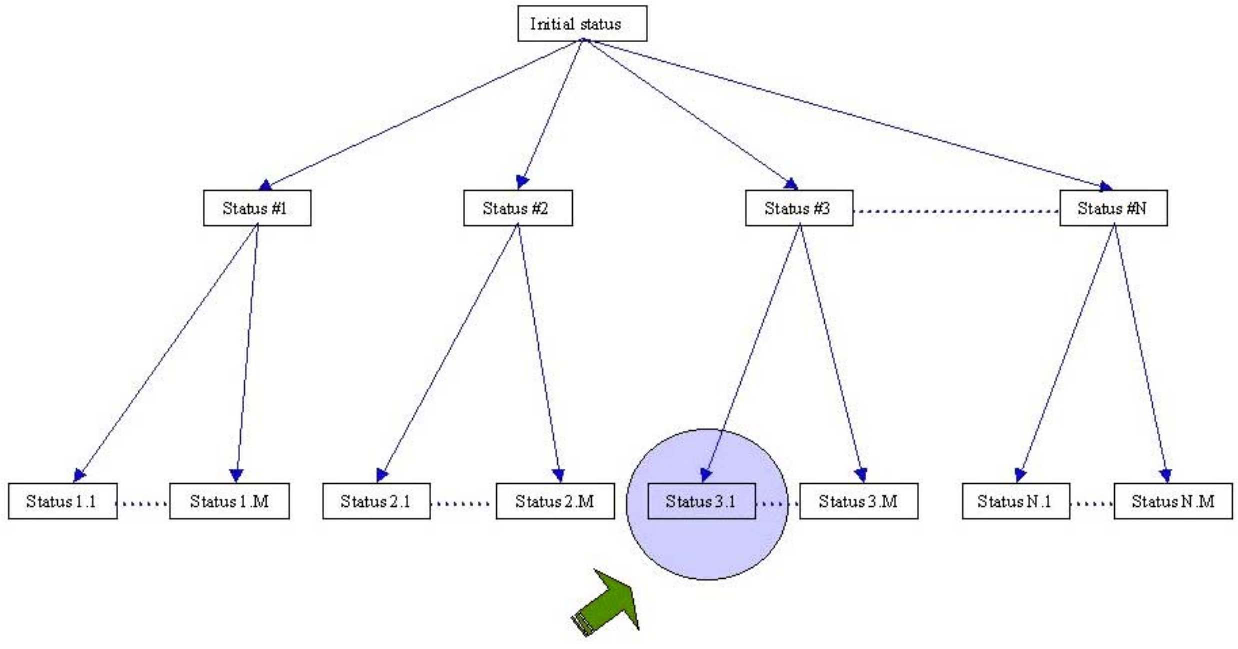
STATES NUMBER REDUCTION

With the application of a heuristic algorithm, we will be able to make the search process shorter.

Our heuristic algorithm will try to establish what is the minimum unit number from which we should start the intelligent search, by discarding previous non-successful state. The factors that we use to reckon the initial state are: the highest calibre of the available units, the effects to obtain and the lowest dimension of the targets set. These data represent a profitable situation from which we can calculate the minimum time to execute a firing action. With this minimum time and taking into account the targets number and the plan duration, we can get the minimum number of artillery units from which we can start the intelligent search.

This simple algorithm will save several hundreds of previous states, which will never fit the plan requirements.

With a similar technique, we know before starting the search, in some cases, if there is a possible solution within the search tree, which prevents starting a long search with no solution.



Initial status

Results and applications

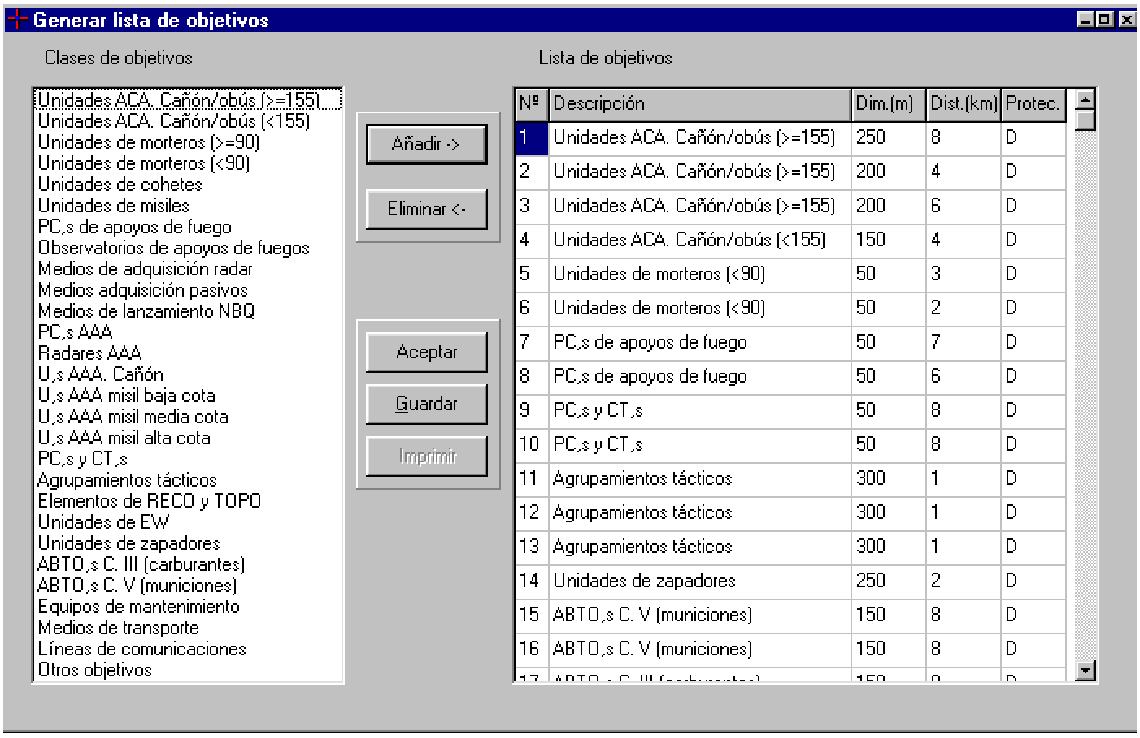
Example

For a preparation plan with duration of eleven minutes, with twenty targets and five artillery battalions, looking for a neutralisation degree of 15%; the software prototype takes eleven seconds to check 135,000 different distribution states. Successfully, the computer gives a solution with a minimum of artillery units usage.

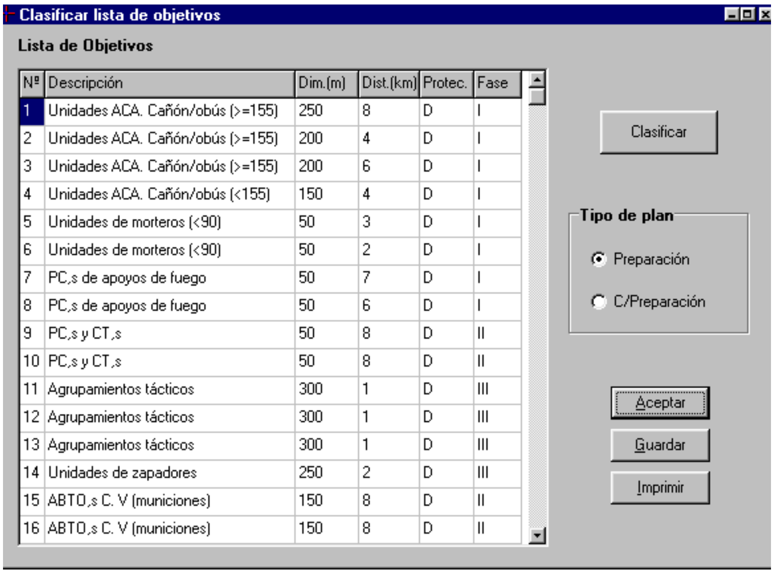
To use the software prototype it is necessary to accomplish five steps:

1. To enter the data of the plan

2. To generate/load a targets list

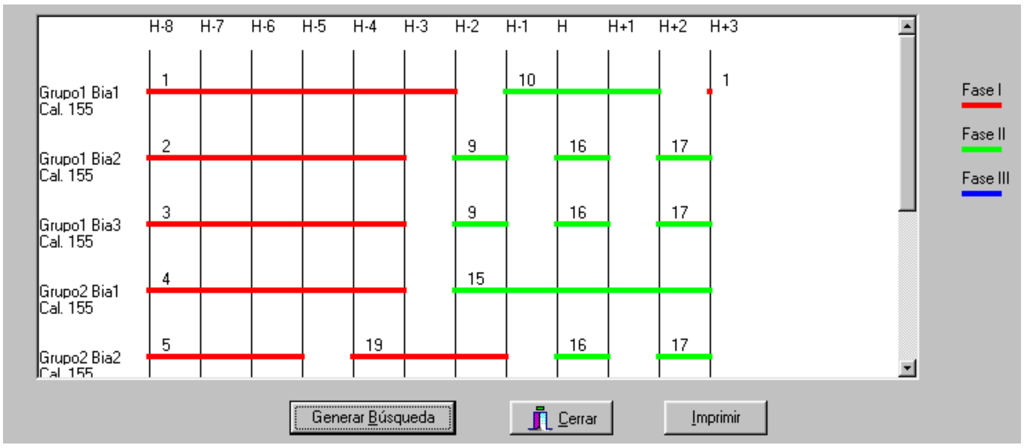


3. To classify the targets list



4. To generate/load the list of available artillery units

5. To seek the solution



Applications in decision support

The way in which the conceptual tools have been used to solve the artillery planning process could be integrated in any Command and Control system related to the field Artillery Command Post. This study can be taken into account in the future artillery Command Post at the Division level or in the current Spanish 'PCGACA' R&D program which is developing a computerised Artillery Command Post at the level of Brigade.

One of the most important advantages that this work can offer to a computerised Artillery Command Post is the possibility of making a plan with computer aided control. This characteristic implies the automatic reorganisation in real time if the scenario changes unexpectedly while carrying out the execution of the plan. Therefore, we can obtain in a few milliseconds a new plan that fits the requirements of the new tactical scenario.

Applications in simulation

Nowadays, there is no way to evaluate the different plans that we can generate by following the planning making rules. There are simulations programs, such as SIMACA ('Field artillery simulator') that will be able to permit in a near future the generation of a scenario in which an artillery preparation or counterpreparation plan is to be made and executed.

With an accurate application of the algorithms developed in this work, it would be possible to evaluate how good is the solution given by the human team, compared to an optimum plan calculated by the computer.

Future project

We have solved the artillery planning process by making a plan that must be executed in a prefixed time. We can try to generalise the use of AI procedures in other planning contexts.

In our current work we have used the following elements:

- Units: with their specific characteristics
- Targets: with their specific characteristics
- Plan: with its characteristics and special making rules

We can try to generalise by making an abstraction of these elements, that we can rename now as:

- Resources
- Tasks
- Project

We could use the same techniques in order to obtain the plan of any project that uses these three elements. For instance, we can solve a management project or a computer science project in which we want to know the plan that fits any of the following possible requirements:

- Minimum use of resources
- Minimum time in which the project could be finished
- Minimum cost in a prefixed finishing time

Thanks to the object oriented programming techniques that have been used to obtain the prototype developed in this work, it wouldn't be difficult to reuse them in this new investigation line.

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Incorporating Aspects of Human Decision Making in Task-Network Simulation Tools

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Abstract: In this paper we describe three ongoing projects intended to improve the representation of human decision-making in military simulations. Each project addresses a different aspect of decision making. The first project extends the functionality of the Improved Performance Research Integration Tool (IMPRINT) by allowing the user to create a detailed model of a goal-oriented human agent. A simulation running in IMPRINT predicts what the human is likely to do based on the currently relevant goals and the status of other parallel simulations. The focus of the second project is to predict the likelihood of a particular decision being made successfully given the quality of information available at the time the decision is made. The underlying idea is to use a task-network model to represent *who knew what and when*. In our third project, we are working to represent the human decision-making process in time-pressured, stressful situations. We have turned to Klein's theory of the Recognition-Primed Decision (RPD) as a model of what people actually do in such situations. RPD theory differs from traditional, analytical theories of decision making insofar as the emphasis lies on situation assessment rather than the comparison of options and thus poses a novel set of computational challenges.

1. Introduction

Decision making is a defining feature of human performance and, as such, deserves special attention as the human element is incorporated into both virtual and constructive simulations. Unfortunately, traditional models of decision making often overlook the impact of goal orientation, posit an agent with perfect information and assume that the agent will choose rationally among alternative courses of action. The resulting simulations tend to manifest brittle behaviours and yield results that are difficult to generalize.

Below we describe three ongoing projects intended to improve the representation of human decision-making in military simulations. The first project extends the functionality of the Improved Performance Research Integration Tool (IMPRINT) by allowing the user to create a detailed model of a goal-oriented human agent. A simulation running in IMPRINT predicts what the human is likely to do based on the currently relevant goals and the status of other parallel simulations. The human-performance models that underlie an IMPRINT simulation are thus far more dynamic than those traditionally associated with task-network approaches. Moreover, the relation between goal-orientation and decision-making is explicitly represented in the task network at a theoretically appealing level of abstraction. The second project focuses on the quality of information that drives decision-making. We use a task-network model to represent the flow of information from agent to agent together with measures of information *frequency* and *volatility* to predict the effectiveness of the decision. Finally, the third project is an attempt to develop a computational model of Klein's (1989; 1993; 1998) recognition-primed decision (RPD). The RPD model purports to describe what people actually do when they make decisions in stressful, time-pressured environments. The RPD model emphasizes experience and situation assessment as the central mechanisms in the decision-making process. Accordingly, our computational analogue is built around a recognition routine together with a mechanism to support reinforcement learning (to allow the synthetic agent to learn from experience) and a feedback loop that allows the agent to make more finely grained assessments of the situation.

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Although our work on decision-making resonates with efforts in cognitive modelling, we are not developing a cognitive architecture. Rather, we are working to enhance the capabilities of existing task-network modelling tools by representing a few select aspects of cognition that are especially germane to decision-making. Our goal is to improve the realism of human performance models. At the same time, however, we realize that increased fidelity should not compromise usability nor should it obscure the connections between computational models and the descriptive models of cognitive psychology they represent.

In the next three sections of this paper, we describe our projects in greater detail and we indicate how each manages to strike a balance between increasing fidelity, usability and theoretical face validity. We then conclude with a more general discussion of our task-network based methodology and the advantages we see in it.

2. Modelling Goal-Directed Behaviour

Traditional task-network models of human performance have been criticized for their inability to represent and predict the dynamic aspects of goal-directed behaviour. Although they leave room for stochastic variability, task-network models of human behaviour are typically constrained by an *a-priori* specification of the processes the agent will perform in order to complete a well-defined mission. Thus, the tasks and cues that prompt decision-making and even the decisions themselves all follow in predictable lock-step with the scenario that drives the simulation.

The shortcomings in the traditional approach are evident when we consider how one might model a scout helicopter pilot who has a primary mission to conduct reconnaissance of a target area. The pilot's primary goal is to fly a well-defined path and to use a variety of sensors to collect data. But if during that flight the pilot identifies an incoming threat (possibly originating from a parallel radar simulation model), the goal will change immediately from "fly and gather data" to "evade and survive." This goal change dictates a change in tasks as the pilot suspends his execution of the pre-planned flight path and begins new tasks to conduct high-speed evasive maneuvers.

In the foregoing example, events in the mission scenario as well as events in other linked simulations can change the pilot's goal and the associated goal-oriented behaviour. Moreover, there is a dynamic interaction between goals, in which a high priority goal can suspend, halt, or restart a lower priority goal. Consequently, the execution sequence of goals cannot be scripted even though specific tasks required to execute a specific goal can. Such non-scripted behaviour is difficult to represent within a traditional task-network approach.

To address this challenge, the Air Force Research Laboratory extended the basic capabilities of Improved Performance Research Integration Tool (IMPRINT) so that it could be used to predict goal-oriented human performance in a complex, external simulation-driven environment. The basic features of IMPRINT as a task network modelling tool remain the same: the user describes a mission by breaking it into smaller "sub" functions. A mission is represented as a network of functions using a point and click GUI. Each of the functions is then further broken down into a network consisting of other functions and tasks. Finally, users estimate the time it will take to perform each task and the likelihood that it will be performed effectively.

By executing a simulation model of the mission, users can study the range of results that occur in the mission. A description of the variability of each element can be obtained for further analysis. Additionally, at the completion of the simulation, IMPRINT can compare the minimum acceptable mission performance time and accuracy to the predicted performance. This determines whether the mission met its performance requirements.

We expanded IMPRINT to represent goal-oriented behaviour by implementing two fundamental changes. First, we enabled users to represent the tasks that a human would perform in response to a goal as separate task networks, not linked to the mission level model. Each of these networks is then associated with an initiating, or triggering, condition. An example of a triggering condition might be that a threat has approached within sensor range. The IMPRINT user lists the goals and enters the arithmetic and logical expressions that specify when each goal will be triggered (see Figure 1).

Second, the goals must be prioritized so that they interrelate properly. For example, our helicopter pilot will have one overriding goal—to accomplish the assigned reconnaissance mission. With the advent of a threat, however, the pilot's immediate goal will change to "evade threat and survive." After the pilot has successfully evaded the threat, he may resume the mission at the appropriate place on the flight path. Alternatively, the second, lower priority goal of "attacking target" may be triggered by a target becoming available. To complicate this situation, if a target appears during the prescribed mission, and the pilot attacks it (the "attack target" goal) and then a threat appears (the "evade goal"), the pilot will immediately abort the attack and begin evasive maneuvers. Thus the pilot aborts the lower priority goal when the high priority goal is triggered. In IMPRINT, the user can represent this behaviour through the Goal Action Matrix (see Figure 2).

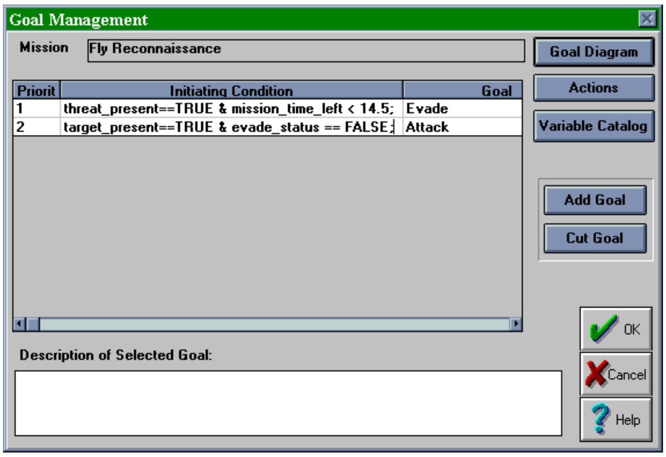

Figure 1. Goal Management: Triggering Conditions

In this simple case, there are only two goals and they are mutually exclusive. In a more typical case, there might be several goals that compete for the pilot's attention. Therefore, the tool must have a robust capability through which users can specify which goals are most important and, once triggered, whether the tasks associated with ongoing lower priority goals are aborted or interrupted.

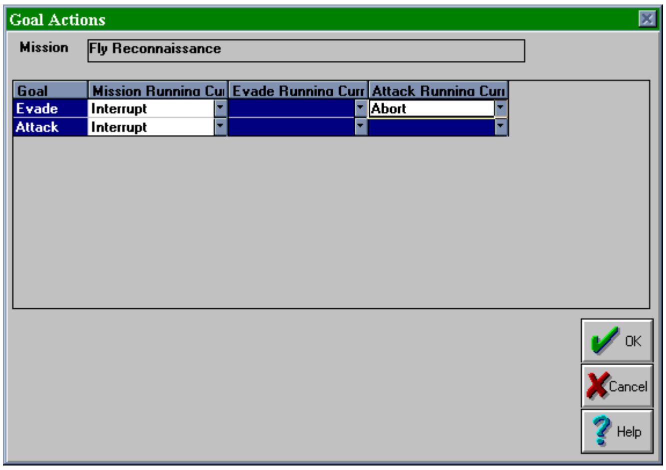

Figure 2. Goal Action Matrix

The capabilities described above have been exercised in an IMPRINT simulation of a pilot's time-critical target mission. These models were run against pilot-in-the-loop scenarios and compared favourably (the details of pilot case study and some discussion of the results can be found in (Hoagland et al., 2001)**.** Moreover, the construction of the human performance models in IMPRINT is relatively straightforward; goal-directed behaviour can be specified in terms that follow from interviews with subject matter experts, cognitive task analyses, doctrine, or even simple intuitions about how the agent will behave. This makes such models of human performance more perspicuous and lends a degree of face validity to the models. We will return to this point in our conclusion.

3. Information-Driven Decision-Making

The notion of an "information-driven" decision grew out of Army Research Laboratory's need to understand how the increasing amounts of information available from the "digital" battlefield affect command and control. Several human-performance models were developed under an Army Science and Technology Objective to address organizational, doctrinal and material changes within various command and control structures. The information-driven decision was implemented in a model of the sensor-to-shooter process.

The sensor-to-shooter process was modelled because it is well-constrained and yet still critical to successful offensive operations. The model itself consists of a single task-network, implemented in the Micro Saint simulation language. The network encompasses planning, rehearsal, execution and assessment phases. Model execution begins with a Fire Effects Control Centre (FECC) receiving an operations order from a higher echelon. Execution continues with a planning phase followed by a rehearsal phase. The planning phase consists of tasks involving observation of the current terrain,

assessment of enemy and friendly forces as well as the development of potential courses of action. After planning is complete, the plan is disseminated and the model moves into mission rehearsal. Following the rehearsal phase, the model determines probabilistically whether adjustments need to be made to the plan as a result of the rehearsals. The plan (revised or not) is then disseminated and the models begins the execution and assessment phases.

The mission execution and assessment phases represent a battle in which several different functions are performed in parallel. Personnel in the FECC monitor and assess the progressing battle. At the same time, pre-processed sensor data are collected by unmanned aerial vehicles and other sensors to be processed by personnel in ground stations. Meanwhile, the fire unit delivers lethal and non-lethal effects. During the battle, targets of opportunity are identified by intelligence and passed to the effects providers for targeting.

The focus of the model is information flow and communication, particularly when that flow leads to a decision. In order to represent the flow of information, five types of information are specified within the task network model, with each type composed of a variety of elements. These five types follow from the Army's five key "nodes" for testing a developed course of action while the elements give content to each node. There are more than 20 individual "decision points" in the network. Each decision point has been analysed in terms of the information elements required to make the decision. In this way we can determine whether the soldier (or soldiers) making the decision has had recent access to the required information. As operators perform the model tasks they are exposed to the information associated with that task. The model records the time and specific elements by operator as the tasks are executed. When a decision task is reached, these exposure times are used together with information decay rates to calculate the probability that the information is accurate enough to support a high quality decision. Two factors about each element determine the rate of decay: the frequency and volatility of the changes. For example, if the enemy force is moving very quickly, the "*where*" element of the Enemy Completeness node will change often and dramatically. Therefore, recent exposure to this element is necessary to make the information valid at the point of the decision. The *who* element, on the other hand, may rarely change, and have no volatility. In other words, the quality of the *who* information remains relatively stable even during infrequent exposures. Each of the information elements can be assigned a category (based on the operational profile), and the resulting assignments are used to decay the information quality. These factors, along with other attributes such as fatigue, training, experience and operator workload, can then be used to predict whether the soldier made an effective and timely decision.

The model was exercised to investigate whether an organizational change in the FECC would shorten sensor-to-shooter timelines. (The results are described in (Wojciechowski, Wojcik, Archer, & Dittman, 2001)). Although decision-making was not considered in this pilot analysis, the model still supports the analysis needed to determine whether the decision makers in the FECC are getting the right kind of information at the right time. Moreover, the techniques described above represent an explicit attempt to model and quantify uncertainty on the synthetic battlefield. While most models of decision-making under uncertainty focus on probability theory as a formal means for reasoning with uncertain information, few models address the source of uncertainty. For instance, it has become common practice to use Bayesian belief networks to model an agent's belief that a situation S holds given an observation of event E. But in order to compute Pr(S|E) it is necessary to know the prior probability of E given S which is most often "…assumed known through an understanding of the situation-event causality"(Pew & Mavor, 1998, p186). This is a non-trivial assumption. The techniques that underlie our models of information-driven decision-making have the potential to supply these prior probabilities as measures of information uncertainty and can thus lead to more robust models of situation awareness and decision-making.

4. A Computational Model of the Recognition-Primed Decision

The RPD model falls under the rubric of Naturalistic Decision-making, a school of thought that pushes the study of decision-making outside the controlled environment of the laboratory and "into the wild" where decisions are made under uncertain conditions, with incomplete information, severe time pressure and dramatic consequences. The RPD model explains how people can use their experience to arrive at good decisions without having to compare the strengths and weaknesses of alternative courses of action. The claim is that people use their experience to "size up" a situation, and thus form a sense of "typicality." Typicality amounts to the recognition of goals, cues, expectancies and a course of action

(COA). Where classical decision theories postulate an analytical agent who carefully considers a host of alternatives, often against a background of perfect information, the RPD model postulates an agent poised to act who depends on his expertise to assess the available information and identify the first workable alternative. Figure 3 shows the flow of activities in the RPD model.

Although the RPD model has gained wide support among psychologists, both empirically and intuitively, it has yet to be explicitly represented in military simulations. This is due in part to the fact that human decision-making, when it is represented at all, is often treated as a ruled-based phenomenon or as a process of rational choice. The RPD model, by contrast, presents a different picture of the human decision-making process and entails a different set of computational challenges. Hunter et al (2000) identify three elements essential to a computational model of the RPD: First, there must be a representation of the cues in the environment that prompt the recognition of a situation. Second, there must be a "collection of situations"—a computational analogue of long-term memory. And third, there must be some sort of "pattern-matching" routine to recognize situations. We describe our approach to each element below (a more detailed discussion can be found in (Warwick, McIlwaine, Hutton, & McDermott, 2001)).

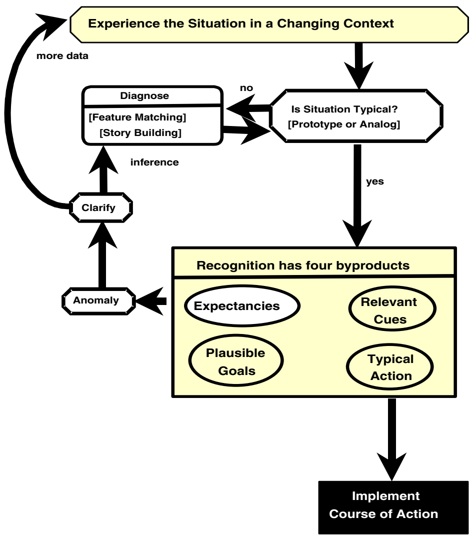

Figure 3: The RPD Model Diagnostic Version

4.1 Cues

We represent situations in terms of a fixed set of features from the decision-making environment. The value of each feature is, in turn, stored in a "working memory" array that is subject to the vicissitudes of the agent's perception and attention management (e.g., an agent might fail to notice a change in a feature because he is distracted). The features themselves might be the values of variables taken directly from the decision-making environment or they might be subject to some sort of pre-processing routine that transforms constellations of cues into more meaningful judgments about the situation.

4.2 Long-Term Memory and Recognition

Our approach to long-term memory and recognition follow directly from Hintzman's *multiple-trace memory model* (1984; 1986a; 1986b). Unlike other memory models that posit a store of generic concepts or *schema*, Hintzman's model treats long-term memory as a store of individual experiences. The basic idea behind a multiple-trace model is that each experience an agent has leaves behind its own *trace*, even if that experience happens to be exactly like another experience the agent has had. In our computational analogue of the RPD, the decision maker's long term memory is represented by a two-dimensional array. Each row in this array represents an individual decision making experience (i.e., a situation that prompts recognition and the so-called *by-products* that follow from recognition). Together, the rows of the long-term memory array record the variety of experience an agent has making a given decision in a given environment under changing circumstances.

Recognition in a multiple trace model is a process of comparing a given situation to the portion of each trace that represents a remembered situation, computing a *similarity* value for each trace and then using those values to form an "echo" that represents the associated by-products. Intuitively speaking, the similarity values are used to compute something like a weighted average of the contribution each experience in long-term memory makes to recognition. But because multiple rows of long-term memory contribute to the *echo*, it is not always clear what has been "recognized." For example, we might have several rows in long-term memory that happen to be equally similar to the current situation but, for whatever reason, are quite different from one another in terms of the association they represent between situation and by-products. And yet each of these rows will contribute to the *echo*. Consequently, we apply a simple statistical analysis to determine when an echo reflects a genuine association between

situation and by-products and when it is merely a reflection of the “noise” that results from having multiple rows of long-term memory contribute to the *echo*.

We find the multiple-trace model of long-term memory intuitively satisfying for several reasons. First, because recognition depends on a measure of similarity rather than, say, a perfect match between situations, recognition can be “fuzzy.” This makes decision-making behaviour more robust insofar as incomplete information can still lead to recognition. Second, the episodic nature of long-term memory provides a ready mechanism for “learning” from experience. Toward that end, we have implemented a simple reinforcement routine so that new experiences (i.e., traces) can be added to long-term memory at run-time thereby allowing the synthetic decision-maker to learn from his experience as the simulation is repeated. Third, the structure of long-term memory and the mechanics of recognition allow the computational model to be specified and understood in theoretically familiar terms; there are no “hidden layers” to train and no parameters to tune. Rather, long term memory encodes the cues and by-products that are specified by the human decision maker during a cognitive task analysis. Likewise, the recognition routine is sensitive to overt effects such as changes in the decision-maker’s workload and shifts in cue saliency that can occur from situation to situation. Finally, the multiple-trace model of long-term memory is computationally straightforward. Not only does this facilitate software development, the straightforward structure of long-term memory makes it easier to see how the computational model realizes the psychological theory it purports to represent.

Meeting a standard of theoretical face validity is the greatest challenge of this project. Indeed, it is one thing to evaluate the model’s output (e.g., Does the model make reasonable decisions?), but it is quite another to determine whether that output is produced in a psychologically sound manner. Our approach to this challenge has been iterative; as we understand more about the RPD model we implement additional features in the computational model. We then exercise the model, examine its output and, more importantly, the process by which the output was produced. Finally, we sit down with a team of cognitive psychologists to review that process. This last step has led us to refine both the computational model and our theoretical understanding of the RPD. At present, our computational model is able to learn reasonable associations between situations and courses of action. We have also developed prototype interfaces that will, with suitable CTA data, support the development of arbitrary RPD “decision nodes” in a task-network modelling environment. The next steps are to implement a more robust feedback routine for the evaluations of expectancies and to gain a better understanding of how model performance changes with experience and workload effects.

5. Conclusion

Throughout this paper we have alluded to the significance we attach to face validity and the direct relation between our “micro models” of decision making and the aspects of human performance they represent. The sense of significance here follows from our attempt to address a fundamental tension in the effort to incorporate the “human element” in virtual and constructive simulations. On the one hand we want high fidelity simulations; often this desire is expressed as a need for “intelligent software agents.” On the other hand, however, we want our simulations to yield results that are predictive and, perhaps, even diagnostic of situated human behaviour. Unfortunately, the techniques from artificial intelligence marshaled in support of intelligent software agents do not always generalize to human performance, while the integrative architectures of cognitive modeling are not always widely applicable. We propose a middle ground—theoretically grounded representations of human performance that describe, at various levels of abstraction, what real people do in real situations. We believe the task network approaches described above are a good first step toward that goal.

6. Acknowledgments

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A Low Cost Dismounted Infantry Trainer Derived from Gaming Technology

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1. Summary

This report gives the reader with an insight into the potential of state-of-the-art computer games and how they might be employed for certain aspects of dismounted infantry training. A description of an example system, its configuration and execution for training purposes and the modifications which can be made to meet individual user requirements are all discussed below. It is not the intention of the author to define the limits of the system but simply to illustrate what uses might be made of it in order to stimulate ideas and discussion within the modelling & simulation community.

2. Dismounted Infantry Simulation

2.1 Conventional Techniques

Dismounted infantry training is a highly specialist area of military simulation. Where facilities exist, the majority consist of high cost tools and trainers focussing on equipment use and procedures. There is a commonly held belief that skills and techniques in the art of infantry combat and tactics can only be taught effectively in the field, and there is little that an individual can learn using computer-based training (CBT) techniques. However, the costs involved in live training suggest that this is becoming an idealistic viewpoint and that a low cost method of augmenting infantry training by other methods is desirable.

Conventional CBT is one method employed by armed forces around the world to convey certain knowledge and methodology to its staff in a simple "point and click" environment. For some areas of military training, this provides an effective medium, especially when resources and instructor time do not allow training to be taken at the trainee's pace. However, CBT applications are often limited in their "interactiveness" and do not always engage the user in the learning process.

2.2 A New Approach

What would a notional "generic" infantry simulation provide? Firstly, it should provide a cost-effective alternative to specific elements of live training. Secondly it might provide a means for individuals or groups to train interactively wherever and whenever the need arose. Thirdly the simulation might contain a variety of training scenarios which incorporate typical situations faced by infantry in the field. The system may even be capable of facilitating some aspects of basic mission rehearsal.

Over recent years the increasing power and affordability of PC computers has provided greater capability for, and wider access to, new and novel methods of desktop training. These concepts, traditionally developed as high tech bespoke systems over many years, can now be more readily obtained by organisations with smaller budgets. But can games be an effective medium to deliver them?

Computer games are designed to entertain. Highly sophisticated gaming concepts rapidly developed but at low unit cost, incorporating the latest technology and advanced programming techniques are what the public buy. The computer game industry has built a multi-million dollar business on the growing power and affordability of desktop PCs by realising the customer's requirements precisely. It is the products resulting from this approach that could directly benefit the dismounted infantry (DI) training community.

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

3. Research at RMCS Shrivenham.

3.1 Areas Of Interest

Research carried out by staff and students at the Royal Military College Of Science (RMCS) Shrivenham has identified several areas of DI training that could be supported by simulation. Areas of interest include the matching of training requirements to the most appropriate method of delivery (for example, the possible use of virtual environments for distance estimation and navigation training), as well as projects such as *"Required Characteristics of Virtual Simulation Tools for low-level Dismounted Infantry Commander Training"* and *"Low Cost, 3D Interactive Networked Training"*. Most infantry simulation projects carried out at RMCS Shrivenham are written from the perspective of serving military personnel who have received such training, not from the point of view of a training provider with a product to sell. It is widely recognised that "gold plated" solutions do not always meet the needs of the user.

Research at RMCS Shrivenham has generally adopted a "user push" methodology instead of the classic "technology pull" approach in order to identify how and where the different forms of virtual training might be usefully employed (or indeed if they are even applicable). It is obvious that computers and simulation will not be useful for teaching all of the skills required by infantry. Much of the research is done to establish and clearly state how and where each type of virtual training can be used, and in what form to develop those skills most effectively. The types of simulation considered range from screen-based CBT to immersive, full fidelity virtual reality (VR) systems, and each skill/simulator combination is examined against several key criteria including ease of training transfer, cost of implementation and so on.

3.2 A Desktop Solution?

It is not the recommendation of this report that the DI simulation system described here should in any way replace live infantry training. Every simulator is designed to develop specific skills and each has its limitations. This system is no different, and this report is simply intended to explain its purpose and describe its potential.

The kind of abilities that could be developed using a game are not ones which might at first appear relevant. It is understood that basic skills such as hand-eye co-ordination and spatial awareness can be enhanced using computer games. Interpretation of and reaction to visual and audible cues in the real world are comparable to those produced by computer games.

Spatial awareness in particular is more closely related to 3-dimensional games because of the way in which the world is presented. First-person perspective, for example, provides perhaps the most realistic view of the world (i.e. down the barrel of a gun). This allows scenery, scenarios and events to be observed from a familiar viewpoint. The key point here is that games are designed to be absorbing and, if they contain carefully crafted and believable elements, users will subconsciously accept what they see and will be immersed in the "world" they are interacting with.

Figure 1 - A 3-Dimensional Player View

The possible uses of computer games are really threefold:

1. The use of specific game types to demonstrate infantry tactics or practice vehicle maneuvers (e.g. action games or tank simulations).
2. The use of games as stimuli for developing specific skills (e.g. the delivery of effective verbal commands, co-ordination & team working, etc.).
3. As previously suggested the development of spatial awareness, hand-eye co-ordination, and so on.

It has even been observed that games such as that which forms the basis for the DI simulator (described in detail later) may help to acclimatise users to specific scenarios commonly encountered by infantry. By becoming accustomed to certain events, this may allow trainees to use the limited time they have on live exercises more effectively. The following list contains examples of particular skills that may be practised using this type of system:

- Hand-eye co-ordination;
- Spatial awareness;
- Voice communication;
- Target recognition and acquisition (including the use of sighted weapons and night vision equipment);
- Threat assessment;
- Visual demonstration of tactics and procedures;
- Demonstration of the effects of close quarters combat in built-up areas;
- Collective manoeuvring and co-ordination of movement;
- Mission rehearsal (where prior intelligence is sufficiently detailed).

In essence, this system would provide a safe and readily available environment containing the required stimuli in which to practice techniques when live training is not practical. ("Training system" is perhaps an incorrect description for this kind of simulator. A "practising system" or "training augmentation tool" may be a more accurate name.)

4. DI Simulation System Elements

4.1 Games vs Simulators

Games are, of course, not designed to provide a platform for research, but many can now be modified and customised using tools and information provided by enthusiasts and games developers over the Internet. This is extremely beneficial for any organisation that has only limited resources with which to develop training solutions.

Desktop computer hardware is constantly increasing in power and capability, as is level of interactivity and sophistication in new games. Multiple players, "intelligent" computer generated entities, realistic playing environments and user-modifiable elements are all becoming standard game features. The stage has been reached where they can rival or even mimic professional simulation systems in both complexity and sophistication, but at a fraction of the price.

"Serious" software systems (both commercial off-the-shelf (COTS) and developed in-house) have been used in research and can provide comparable functionality, but all are expensive and few have been

designed to be accessible to beginners and users with basic Information Technology (IT) experience. Games can provide a means to explore ideas and theories without the need to develop costly bespoke systems over long periods.

4.2 Game Description

The game providing the foundation of the DI simulation is id Software's "Quake 3". This is a "first person perspective shoot-'em-up" and is one of a range of similar games currently available (such as Novalogic's "Delta Force" series and Sierra Software's "Half-Life" games). All of these have a number of features in common:

- First person view of the "world" (battlespace);
- "Point and shoot" controls (keyboard/mouse/joystick or some combination thereof);
- Multiple weapons of a variety of types (some based on actual hardware, some fictitious);
- Simple game objectives (usually to destroy all opposition or to attack some location in the world);
- Weapon effects and enemy behaviour close to that which is perceived to be realistic;
- Multiple players interacting in the same battlespace connected via a local area network (LAN) or via the Internet (WWW);
- User-modifiable game elements (including game speed, weapons and enemy behaviour, battlespace editing and creation, etc.).

Above all, it is the fidelity of the "simulation" and perspective from which the user sees the world that is most useful for DI training. Highly detailed battlespaces that can immerse the user are common in games of this type (often the battlespaces provided with the game are closely modelled on believable scenarios, if not actual real-world locations). The way in which the user observes, moves through and interacts with these scenarios adds a depth rarely seen in high fidelity, high cost infantry simulators.

Quake 3 in particular was chosen as the basis for this system for a number of reasons:

1. It is inexpensive (each copy of the game costs around £30);
2. It will run on standard desktop PCs with little or no specialist hardware;
3. It is easy for users to learn and become accustomed to;
4. It is very simple to configure and use collectively over a LAN;
5. It is currently the most sophisticated and modifiable of all the games of this genre today.

4.3 Simulation Hardware Platforms

The equipment and software used at RMCS Shrivenham has encompassed a variety of fidelity and cost criteria. While not all of the systems described in the table below have been used at the college, distinctions should be made between potential simulation hardware platforms in order to identify their strengths and weaknesses in the field of simulation training:

Attribute	System		
	Game Console	**Desktop PC**	**Bespoke System**
Cost	£00s	£00s – £000s	£000s – £000,000s
Hardware Availability	0 – 1 months	1 – 3 months	6 months – 5 years
Networking Capability?	No (generally)	Yes	User-specified
Customisable System?	No	Yes	User-specified
Permanent Data Storage?	No	Yes	User-specified
After Action Review Facility?	Limited (if available)	Software-dependent/ user-specified	User-specified
Factors Affecting Speed of User Familiarisation	Ease of use and “appropriateness” of software	Fidelity of system, complexity of user interface	Fidelity of system, familiarity with user interface

Table 1 – Comparison of Simulation Hardware Characteristics

In this instance a desktop PC-based solution has been chosen because of the low cost and widespread availability of both the software and hardware required to construct the simulator. Many organisations may already possess the necessary computer systems without needing to invest in any further hardware. For example, the system running the DI simulator at RMCS Shrivenham consists of the following:

- LAN consisting of ~20 Pentium III Windows PCs with OpenGL compatible graphics accelerators;
- Id Software’s Quake 3 (with software upgrade patches* downloaded from the Internet);
- Silicon Ice Development’s “Urban Terror” conversion software (downloaded from the Internet).

*As professionals and enthusiasts develop new additions and tools to the original game, “bugs” (errors in the original code) and incompatibilities sometimes become apparent. Information about them is sent back to the original game developer who will usually release a “patch” (a bug-fixing program) to rectify the problem.

5. Game Customisation For Effective Training

5.1 Degrees Of Modification

Early attempts to adapt games such as id Software’s Quake 1 and Doom for training usually required source code modification in order to customise the game in any way. Quake 3 has been specifically designed to be modified by its users. Scenario editors, battlespace modelling tools, utilities to adjust enemy behaviour and to alter weapon and character appearance are all available on the Internet. Professional modelling tools can be used but not essential. User groups are actively encouraged by game developers to modify their products to increase their longevity, and countless websites have emerged to provide software modifications, information and discussion forums. Code-level modification is not often required to achieve the desired result – it is likely that a tool for that purpose may have already been written and made available on the Web.

The degrees of modification can be generally grouped (in an increasing order of complexity and required user skill) as:

- Adjustment of in-game settings (user controls, character appearance, playing conditions, level of aggression of computer generated forces (CGF), etc.);
- Battlespace creation or “world building” (using supplied or downloaded game editors);
- CGF behaviour editing (using tools downloaded from the Internet);
- Character creation (using downloaded tools or COTS modelling software);
- Game engine modification (using downloaded source code released by game developers);
- “Total Conversion Mod” creation (using existing and writing new source code to transform the nature and behaviour of the game itself).

The final point on the above list is perhaps the most significant. This feature is a method of using the game engine purely as a system upon which to run another kind of game. By installing a “mod”, the underlying game code can be manipulated to behave in a different manner. Sometimes the result may simply look different, but often the new system is a complete transformation of the original.

This is a major component of the system in use at RMCS Shrivenham. Quake 3 in its native form is a “fantasy” game (for example, it contains fictional weapons, characters such as animals, aliens and robots with unusual behavioural characteristics and playing areas which are set in space or have unrealistic conditions such as reduced gravity). By using a total conversion mod such as Urban Terror, the game is transformed into an urban combat game with realistic weapons and characters interacting in recognisable scenarios (in the streets of a town, inside a building, and so on).

5.2 Scenario Generation

Battlespaces (or “playing areas”) can be created by the user quickly and easily. The scenarios in use at RMCS Shrivenham were developed without the need for commercial tools or programming techniques, and all that is really required is practice, patience and access to the Internet. Land-based scenarios can be created quickly and easily using one main modelling tool and the amount of detail included in each is left entirely to the designer. The degree of precision involved in world modelling is relatively low (a general rule of thumb is to make object models with approximately the right proportions and appearance, although this usually involves some trial and error).

As the designer gains experience and confidence in world building, the speed with which models can be completed will increase dramatically. The scenario-modelling tool itself (entitled “GTKRadiant”) uses reasonably simple modelling techniques in order to create complex battlespaces. Groups of polygons are created and textured to represent real world objects (e.g. buildings, terrain, foliage, vehicles, etc.) and are enclosed in a boundary to form the playing area.

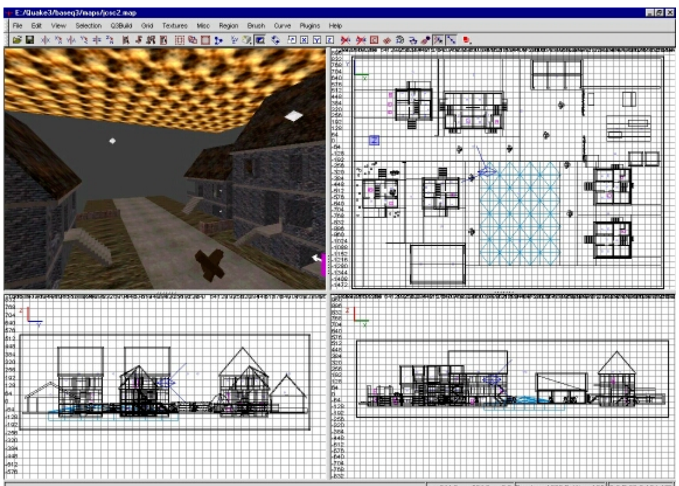

Figure 2 - Modelling With GTKRadiant

The most significant drawback to the modelling tool is its apparent inability to import any type of file other than those specifically designed for the Quake 3 environment. What this means is that all

world building must be done by hand, regardless of whether 3D models of the scenario or its components already exist. Pictures and diagrams must provide the template for a real-world scenario but, by producing carefully textured low complexity models, this process will still be reasonably quick. It is the recommendation of the author to build up a library of models that can be rapidly altered for use in subsequent scenarios.

The finished model is then used as the common playing area for all users, who connect and interact with each other via a central server. All software and models are installed locally on each machine – the server simply acts as a central control point which can connect or refuse entry to players, set the length of each exercise and so on.

6. Training System Performance

6.1 Delivery Of Training Needs

A number of points have been raised which question the method of delivery of training and not the effectiveness of the training itself. It is important for the trainer to consider exactly what is being simulated, how it is being represented and how it will influence the trainee.

Unlike vehicle trainers, there is no "platform" to simulate in a DI system such as this. A car driver can quickly learn to use a steering wheel to control a vehicle simulation. Many weapon simulators incorporate the actual hardware into them to be used as the control interface, which provides user familiarisation in a safe environment. Moving a character around a playing area in order to learn about tactics and procedures may appear strange and abstract to a trainee. It is important to construct scenarios that will subject the user to the necessary stimulation and provide valuable experiences.

On a basic level, one observed effect of using this system is the heightened awareness of players. The nature of the gameplay demands a high degree of self-preservation (i.e. players must look for and react rapidly to hazards in order to survive). The system can illustrate quite effectively how to move and behave in different types of terrain and what actions to take in different situations. Other observations made about user behaviour include:

- Examining and evaluating possible movement routes for safe positions;
- Moving between positions using cover from enemy fire;
- Selecting weapons and fire positions appropriate to the situation;
- Reloading weapons in cover (to minimise player vulnerability during this operation);
- Conserving ammunition and using weapon sights to acquire targets accurately where appropriate;
- Paying attention to audible cues (footsteps, firing weapons, opening doors, etc);
- Frequent verbal communication to ensure effective co-ordination of effort.

The "survival instinct" becomes almost second nature in any computer game, and the level of immersion offered by this type of game drives home the result of a wrong decision very effectively. All of the above field skills are simply demonstrated in the game and may help trainees to perform them more effectively during live exercises.

Tests to measure how satisfactorily the trainees are able to implement and practice the various infantry skills during exercises have yet to be designed and executed (the system at RMCS Shrivenham is still in the development phase).

6.2 Identified Limitations

A number of limiting factors exist in a system such as this. The main points the reader should be made aware of are:

Playing area size: World modelling can be done to produce specific scenarios and, while the complexity of the playing area can be high, the maximum physical dimensions of the playing area are low (a few hundred metres along each side). Long visual ranges are difficult to implement due to the way in which the game engine works, but careful scenario design can minimise the impact this has on training. Game developers are also investigating the use of real world terrain data for modelling, but size limitations of playing areas are probably too restrictive to take advantage of such features (if they are implemented).

However, this may not be important for many of the training tasks described here. The playing areas supplied with the game are sophisticated enough to meet virtually all of the needs of the user. Fighting in built-up areas is well catered for in the supplied scenarios, as is combat inside buildings. Limited dynamic effects are sometimes implemented to add realism (e.g. breaking glass, opening doors) and most real-world features can be found in some form (e.g. furniture in rooms, demolished buildings).

Number of players: The maximum number of players interacting in any one scenario in “Urban Terror” is currently set at 64, all of which can play either using locally-connected PCs or remotely via the Internet. Player numbers are likely to be increased in subsequent versions of the game, and the main limitation is more likely to be the number of PCs available to run the system on.

Computer-generated force (CGF) behaviour: Quake 3 claims to include some of the most advanced CGFs (or “bots” as they are known) in terms of behaviour and autonomy. However, when playing the game they still behave in an undisciplined and slightly unbelievable way. Aimless wandering before engagement, suicidal attacking after and little tactical “ability” throughout all detract from the seriousness of the exercise, but adjusting the bots’ skill level can still provide the users with a challenging fight.

Tools do exist which can alter character performance and behaviour but these are crude and may not improve the situation significantly. Code-level modification is really required to develop more SAF-like characteristics (or, alternatively, employ human players to provide opposing forces).

Weapon effects: All weapons (other than the player’s knife) are based on small arms. Pistols, sub-machine guns, assault weapons and sniper rifles are all provided for the player to choose from, but only one (the grenade launcher) has any obvious ballistic characteristics. Little is known about the accuracy of the various weapons’ performances, but it could be argued that over short distances ballistic droop is negligible. While projectiles and explosions mark surfaces, bullet deflection is not modelled and battlespace features remain intact at all times. Such dynamic terrain effects are costly to produce and are unlikely to be included in the recent future.

After-action review (AAR) capability: The game has the capability to record and replay the action from each user station, but playback can only be done on each individual user station and not as a group. However, this suggests that all of the data required for a typical AAR is generated (personnel movements, shots fired, kills, etc.). If this is correct, there is no reason why a program could not be written to gather this data and present it in a more meaningful way.

Interoperability: As with the potential for an AAR facility, interoperation with other simulation systems (using DIS or HLA, for example) is, in theory, possible. The game is designed to exchange information between player stations using the standard TCP/IP network protocol. With time, money and effort the system could be adapted at code level to communicate using common simulation protocols. However, before embarking on such a mammoth task, the implementers should ask themselves if it is absolutely necessary for the types of training suggested in this report.

It should also be noted that there is little chance of a game such as this being developed specifically for this purpose. The entertainment industry currently does not see the need for games to interoperate with other applications. Each game is unique in its design and implementation, which not only restricts cross-platform interaction but also forces users to upgrade to a new version every time one is released, thus keeping the manufacturers’ profits healthy.

7. The Next Step?

The next step is entirely for the reader to decide. The potential for a cheap but effective training system is there. What is required now is for the modelling and simulation community to consider how it can best be used. Games borrow heavily from simulations of all kinds, learning equally from developments and mistakes, as well as making some unique additions of their own. It would be foolish to ignore an industry rich in experience and expertise when it is capable of producing software that can deliver so many experiences to the user at such a modest price. Surely that is the ultimate goal of any simulation provider.

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Une plate-forme intégrée autour du noyau DirectIA pour la simulation militaire – Résultats d'une étude reproduisant un exercice tactique

An Integrated Platform for Military Simulation Based on the DirectIA Kernel: Tactical Exercise Reconstruction Results

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1. Définition de la problématique

La simulation est devenue ces dernières années un outil de première importance pour le domaine de la défense, tant pour la formation et l'entraînement des forces que pour l'ingénierie, la mise au point de la doctrine d'emploi, la planification ou l'acquisition.

Les applications de simulation se heurtent à de nombreux défis technologiques, parmi lesquels la modélisation du comportement humain, indispensable à l'automatisation d'une simulation. En effet, actuellement, l'environnement tactique (forces alliées, neutres ou ennemies) d'un système modélisé est représenté de façon simpliste, et souvent généré par un opérateur. Ceci peut être très lourd lorsque le scénario de la simulation est complexe, comme dans le cas d'un entraînement d'état-major. Ainsi, certains exercices OTAN peuvent monopoliser des centaines de personnes pour fournir l'environnement tactique nécessaire.

L'automatisation de cet environnement tactique (CGF *: Computer Generated Forces*) est donc un enjeu important pour la simulation. Malheureusement, la modélisation du comportement humain est complexe et encore mal maîtrisée, les outils sont rares et leurs capacités généralement limitées.

L'automatisation des entités d'une simulation repose sur la capacité de ces systèmes à décider de manière autonome de leur comportement. Autrement dit, les agents autonomes disposent d'un agent décisionnel capable de sélectionner la meilleure action à tout instant en fonction de la situation perçue (Figure 1).

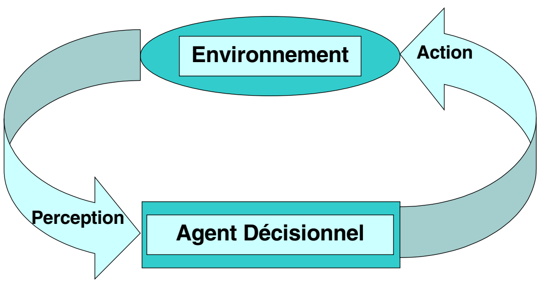

Figure 1 : Le problème général de la décision

Cette capacité de sélection de l'action se dérive en plusieurs sous-problèmes qu'un agent décisionnel doit être capable de résoudre :

– ***Générer un plan d'action*** : L'agent décisionnel doit être en mesure de prévoir le résultat de ses actions pour pouvoir prendre des décisions sur le long terme au lieu de réagir simplement à l'évolution de la situation qu'il perçoit.

Communication présentée lors de la conférence RTO NMSG sur « Défis futurs pour la modélisation et la simulation », organisée à Breda, au Pays-Bas, du 12 au 14 novembre 2001, et éditée dans RTO-MP-073.

– ***Résoudre plusieurs tâches simultanément*** : L'agent décisionnel doit pouvoir résoudre plusieurs tâches, arbitrer entre des buts qui sont contradictoires et, trouver un comportement de compromis entre ces différents buts lorsque cela est possible.

– ***S'adapter aux circonstances imprévues*** : Un tel agent doit pouvoir réagir très rapidement aux contingences qu'il n'avait pas prévues. Il doit également pouvoir tirer profit des opportunités qui se présentent à lui.

– ***Présenter un comportement réaliste*** : Le remplacement d'un opérateur humain par un agent décisionnel nécessite d'obtenir un comportement opérationnel réaliste. Pour cela, il est essentiel d'avoir une méthodologie efficace pour recueillir et pour modéliser l'expertise opérationnelle.

2. Comparatif général de deux approches de la prise de décision

2.1 Description générale des deux approches

La décision dans les systèmes artificiels est un des domaines principaux de ce que l'on appelle l'Intelligence Artificielle (IA) traditionnelle.

Les objectifs de l'IA traditionnelle sont de modéliser les capacités cognitives de l'homme en concevant des systèmes qui « pensent » intelligemment. A cette fin, les travaux relatifs à cette approche ont en particulier porté sur la définition d'un système de résolution de problème universel (General Problem Solver).

Les écueils afférents à l'emploi de l'Intelligence Artificielle classique sont connus et documentés depuis longtemps. Une telle approche nécessite la présence d'un expert pour définir et faire évoluer le système. Tôt ou tard, en particulier dans le cas de situations lourdes, on se voit confronté à une explosion combinatoire du nombre de règles. Pour toutes fonctionnalités additionnelles, cette approche nécessite une ré-analyse complète du processus.

Ces dernières années est apparue une nouvelle approche de la décision dans les systèmes artificiels. Cette nouvelle approche – que l'on qualifie de « située », ne cherche plus à concevoir des systèmes qui « pensent » intelligemment, mais construit des systèmes capables de se comporter de manière réaliste dans leur environnement physique.

L'agent artificiel est donc complètement immergé dans son environnement avec lequel les interactions deviennent prioritaires. Le raisonnement de l'agent ne repose donc plus sur un modèle théorique mais sur le modèles de ses interactions avec le monde physique (cognition artificielle située).

2.2 Principes comparés de raisonnement

Chaque approche s'appuie sur un type d'arbre de décision reflétant des méthodes de raisonnement très différentes (Figure 2).

Lorsque l'on utilise un arbre de décision hiérarchique en Intelligence Artificielle traditionnelle (partie gauche de la figure), chaque nœud du graphe représente un état particulier du domaine étudié et chaque feuille représente un opérateur de changement d'état.

L'utilisation d'un arbre permet de décomposer plus facilement des tâches dont on connaît **a priori** la structure hiérarchique. Le passage d'un niveau de l'arbre au niveau inférieur représente donc un choix dans la manière dont on va décomposer le problème à traiter.

Ce choix est généralement déterminé par des règles de décision associées aux états. Avec une telle représentation, un parcours itératif dans l'arbre de décision permet de générer un plan d'actions.

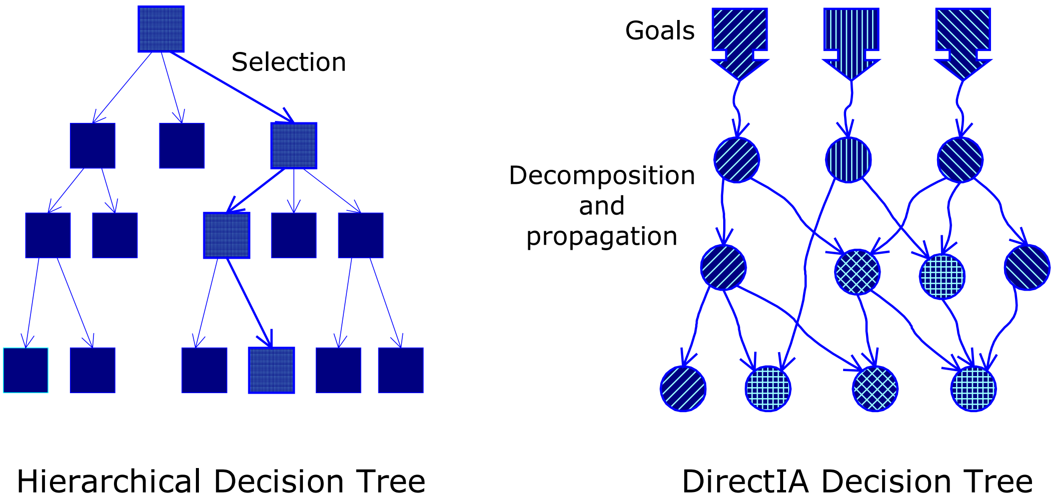

Figure 2 : Comparaison des arbres de décision

La nouvelle approche utilise aussi un arbre de décision mais d'une manière radicalement différente. En effet, au lieu de sélectionner à chaque niveau de la hiérarchie la ou les branches que l'on va décomposer, l'outil propage une activation dans un réseau de comportement se terminant par des actions élémentaires (imitant ainsi la propagation d'activité électrique dans le cerveau). Comme dans un arbre de décision traditionnel, le passage d'un nœud à l'autre est déterminé par des règles de décision. Cependant, au lieu d'utiliser ces règles pour faire un choix, ces règles sont utilisées pour moduler l'activité qui est propagée dans les différents comportements.

2.3 Les modèles de décision issus de l'Intelligence Artificielle traditionnelle

2.3.1 Principes de l'approche classique

Les systèmes de résolution de problèmes (automates d'états finis, systèmes experts, arbres de décision du type graphe ET/OU, etc.) disposent de fonctionnalités générales leur permettant de décomposer chaque problème en une liste de sous-problèmes plus faciles à résoudre, et ceci de manière récursive (approche « Top-Down ») .

Ainsi, progressivement, de tels systèmes sont capables de construire les solutions d'un problème quelconque en combinant progressivement les « morceaux » de solutions obtenues lors des décompositions successives.

Il est important de noter que la description du domaine sous la forme d'états discrets, la manière dont les problèmes sont décomposés et la manière dont les sous-problèmes élémentaires sont résolus, reposent sur une forte expertise du domaine étudié.

La Figure 3 illustre la complexité de l'approche traditionnelle lorsque l'on veut ajouter des fonctionnalités nouvelles dans une simulation complexe. Sur l'exemple, l'ajout d'un nouveau mode d'action oblige le modélisateur à construire un sous-graphe complet.

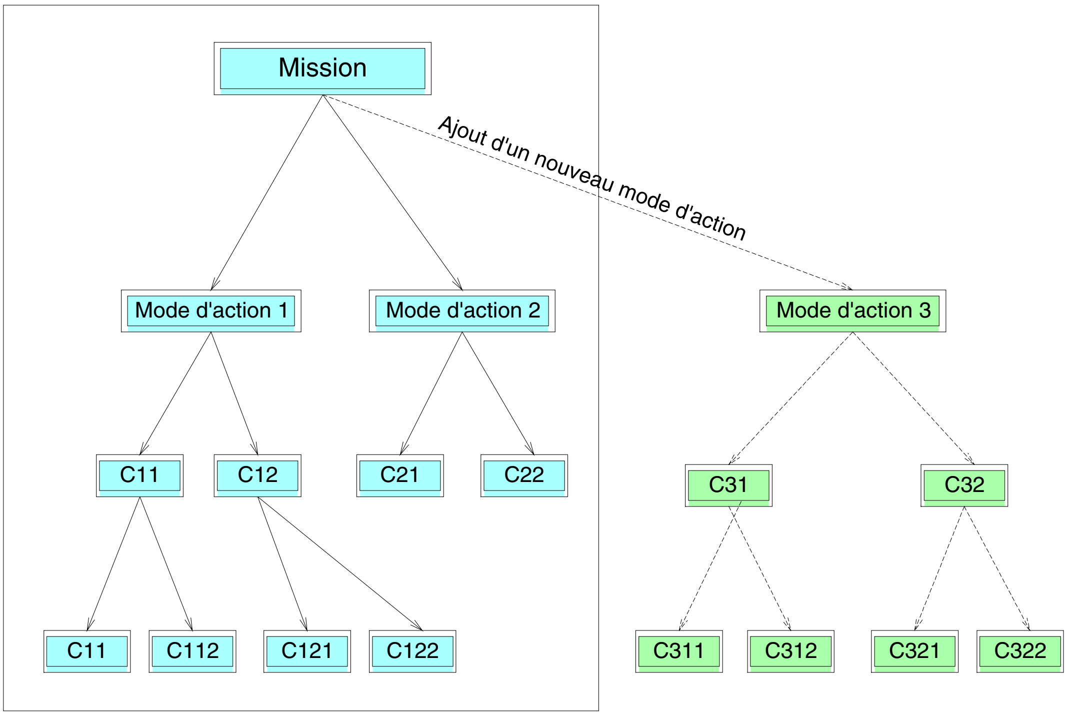

Figure 3 : Exemple d'ajout d'un mode d'action dans un arbre de décision traditionnel

2.3.2 Limitations de l'approche

Si on se rapporte à la problématique générale des systèmes de décision, on constate que l'approche adoptée par l'Intelligence Artificielle traditionnelle présente plusieurs limitations vis-à-vis des quatre besoins cités :

- ***La génération de plan est complexe et peu adaptative*** : L'utilisation d'états symboliques oblige le modélisateur à définir un grand nombre d'états et de symboles pour représenter le domaine de manière réaliste, ce qui conduit généralement à une explosion combinatoire lors de la recherche d'une solution. La modification d'un plan en cours d'action devient dès lors un problème difficile à réaliser en temps réel.
- ***Cette approche ne résout pas ou résout mal les problèmes multi-tâches*** : Un système de résolution de problème considère chaque tâche à résoudre comme un problème à décomposer séparément. Cette technique implique une forte combinatoire dans la recherche d'une solution lorsque les tâches sont interdépendantes. En particulier, la capacité à découvrir des sous-problèmes communs à plusieurs tâches – qui permettrait des choix de compromis – est totalement absente dans ce type de système.
- ***L'agent est incapable de s'adapter aux circonstances imprévues*** : Comme le raisonnement repose sur une représentation discrète et théorique de la réalité physique, les actions planifiées doivent généralement être adaptées pour pouvoir s'appliquer à l'environnement réel. Cette capacité d'adaptation s'arrête évidemment aux circonstances non prévues par le planificateur. En particulier, le système est incapable de profiter des opportunités qui s'écartent du plan prévu.
- ***Le comportement obtenu est généralement déterministe et stéréotypé*** : Pour éviter une explosion combinatoire des règles de décision, les systèmes de résolution de problème sont obligés de limiter le nombre de facteurs pris en compte lors des transitions d'états en états, ce qui correspond à un comportement stéréotypé au contraire des comportements humains qui sont par essence non-déterministes.

2.4 Les modèles fondés sur l'approche situé

2.4.1 Principe de la nouvelle approche

Au contraire des modèles de l'IA traditionnelle, les systèmes issus de l'approche « située » mettent en œuvre des modules de comportement dont la fonction principale est de s'adapter à leur environnement en toutes circonstances.

Cela revient à doter des agents virtuels de comportements adaptatifs et d'une capacité de sélection autonome de l'action, leur permettant de générer des séquences comportementales non explicitement programmées (émergence de comportements complexes).

Pour cela, la méthodologie générale consiste à construire d'abord des comportements élémentaires parfaitement adaptés à l'environnement, puis à ajouter par des couches successives des comportements de plus en plus complexes qui reposeront sur les comportements déjà élaborés (approche Bottom-Up).

En ce sens, il s'agit d'une approche du type " Cognition artificielle située " dans laquelle les agents décisionnels sont immergés dans leur environnement et s'appuient sur celui-ci pour construire leur raisonnement.

Ainsi, l'agrégation des modules s'effectue soit par raffinement des descriptions sans remise en cause des architectures fonctionnelles, soit par concaténation à un niveau supérieur de fonctionnalités.

Les systèmes fondés sur l'approche située sont des systèmes dynamiques mettant en œuvre des espaces d'états continus qui représentent de manière bien plus fidèle le domaine étudié.

Dès lors, le rôle de l'expert est totalement différent de celui qu'il avait en IA traditionnel. Ce rôle se concentre sur l'évaluation du réalisme des comportements plutôt que sur la conception du système lui-même.

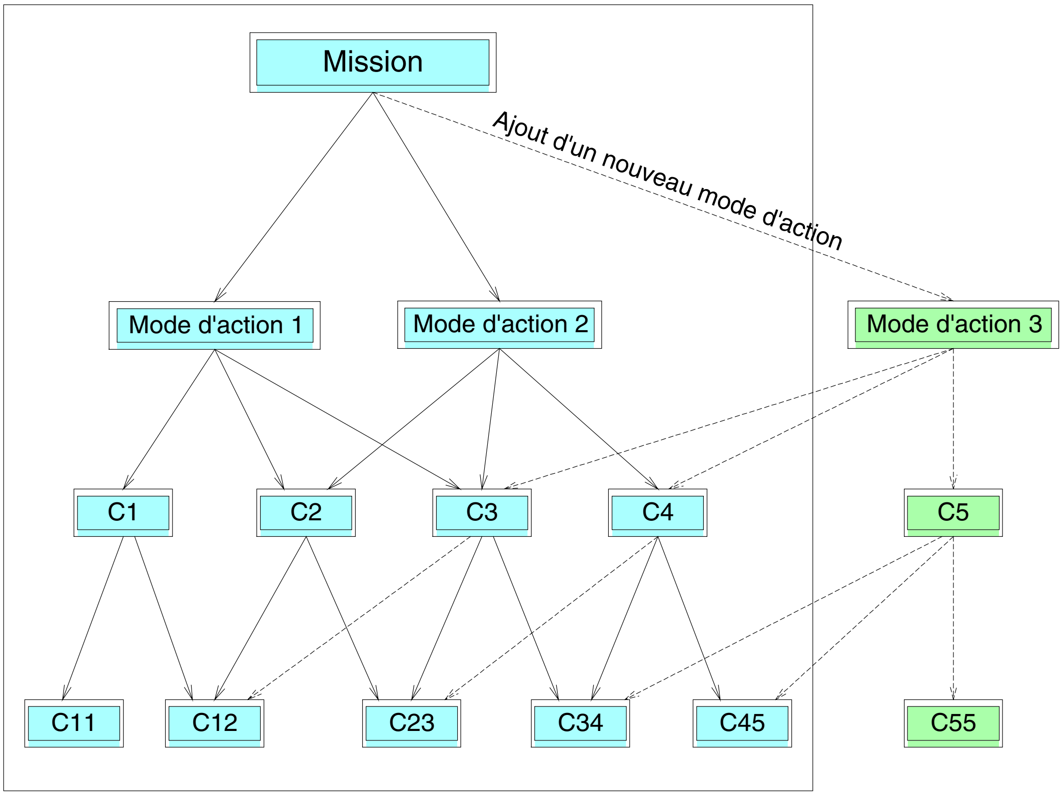

Figure 4 : Exemple d'ajout d'un mode d'action dans un arbre de décision basé sur la nouvelle approche

La Figure 4 illustre la capacité de la nouvelle approche à décomposer plusieurs buts simultanément et à combiner les sous-buts correspondants. En particulier, cette figure montre que l'ajout de nouvelles fonctionnalités peut s'effectuer localement sans remise en cause des processus analysés et sans réécriture complète des nouvelles fonctionnalités. Par exemple, l'ajout d'un nouveau mode d'action ne demande pas une ré-analyse complète car sa modélisation peut profiter de la présence d'éléments déjà modélisés pour les modes d'actions précédents.

2.4.2 Avantages de l'approche

La nouvelle approche « située » de la prise de décision permet de répondre correctement à la problématique de la sélection de l'action :

- ***Les plans d'actions sont adaptatifs*** : Les plans d'actions sont définis dans un espace d'états continu comme la combinaison de comportements élémentaires représentée par un ensemble d'attracteurs du système complexe. Une telle représentation évite le problème de l'explosion combinatoire du nombre de cas discrets à traiter et autorise la gestion de plusieurs alternatives simultanément.
- ***Le traitement de plusieurs tâches simultanément est implicite dans le système*** : Chaque tâche à résoudre correspond à un attracteur particulier dans la dynamique du système complexe. La résolution d'une tâche particulière passe par l'activation de nouveaux attracteurs représentant des comportements élémentaires du systèmes. Chacun de ces attracteurs peut être activé par plusieurs tâches simultanément, ce qui autorise l'émergence de comportement de compromis.
- ***Les systèmes situés sont très réactifs aux circonstances imprévues*** : L'interaction avec l'environnement étant prioritaire, les opportunités et les contingences sont immédiatement détectées et utilisées pour activer des comportements élémentaires appropriés. Ces nouveaux comportements entrent alors en concurrence avec les comportements courants. Ainsi, la détection d'une contrainte peut permettre de générer la liste de sous-buts nécessaires au contournement de cette contrainte.
- ***Les systèmes situés sont capables de faire émerger des comportements non-stéréotypés*** : En effet, les plans d'actions ne sont jamais définis une fois pour toute mais découlent des interactions successives de l'agent avec son environnement. Les facteurs impliqués dans la prise de décision n'étant pas limités à des changements d'états discrets, il est de plus possible d'inclure de nombreux facteurs pour augmenter l'intérêt d'un basculement du système dynamique vers un attracteur particulier. Ainsi, l'introduction de facteurs humains dans le système engendre un réalisme de comportement absent dans l'approche traditionnelle.

2.4.3 Exemple (simplifié) de fonctionnement

Supposons qu'un agent A voit deux agents B (un ami) et C (un ennemi) et supposons que A dispose de trois actions « Attaquer(X) », Eviter(X) et Rejoindre(X) – où X est un agent quelconque – pour décomposer deux comportements contradictoires : « Combattre() » et « Assurer sa sauvegarde() ».

La nouvelle approche permet de définir très simplement un graphe comportemental modélisant cette situation (Figure 5). Ce graphe permet de décomposer deux tâches de comportement en actions potentielles lorsque les conditions des règles de chacun des modules sont activées.

Ici la condition « IPerceive » est une requête offerte par l'outil qui permet de récupérer la liste des agents (ou objets) caractérisés par l'attribut qui est donné en paramètre (ici « EstEnnemi » ou « EstAmi »).

La valeur de l'attribut chez l'agent testé détermine le potentiel de l'action qui sera déclenché par la règle de même que la priorité qui est associée à cette règle. Par exemple, un agent percevant un agent ennemi aura d'autant plus envie de le fuir que celui-ci est ennemi.

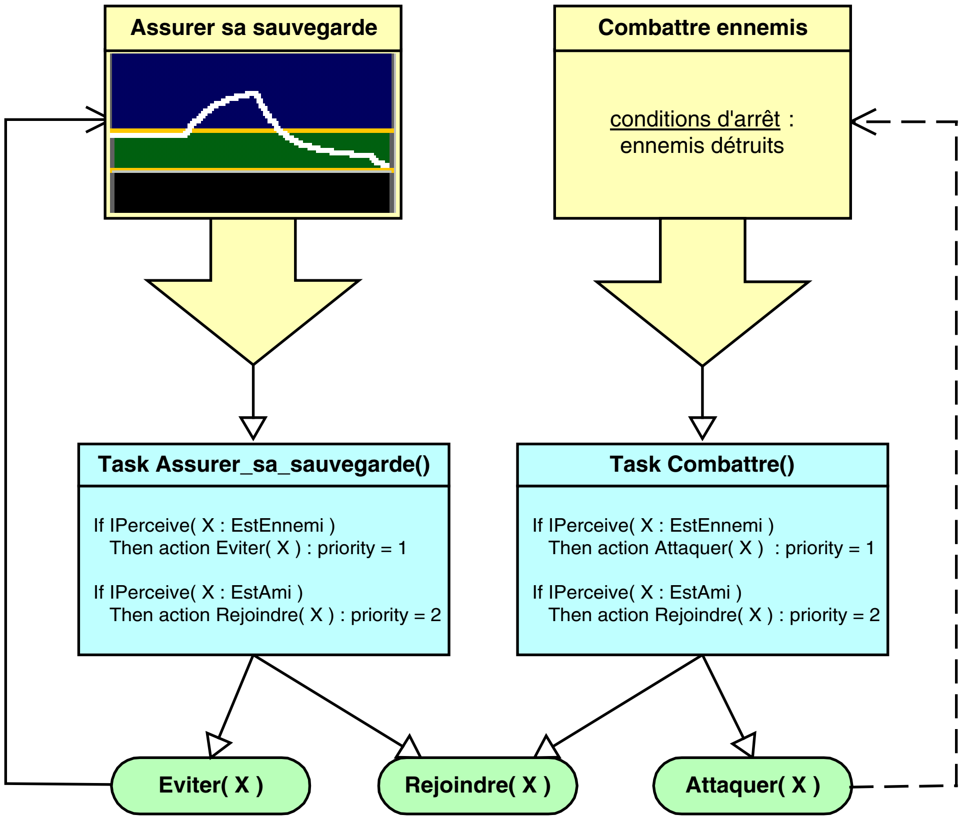

Figure 5 : Exemple de fonctionnement interne

L'outil utilise ce graphe de comportement pour décider de l'action de l'agent A selon les principes ci-après.

La présence d'un ennemi permet de générer de l'activité au niveau de la motivation « Assurer sa sauvegarde » et de la mission « Combattre ennemis ».

Ces deux activités vont être propagées respectivement aux comportements « Assurer_sa_sauvegarde() » « Combattre() ».

Dans chacun de ces comportements, deux règles vont alors se déclencher de manière à activer les actions :

« Eviter(B) » et « Rejoindre(C) » pour la tâche « Assurer sa sauvegarde »

« Attaquer(B) » et « Rejoindre(C) » pour la tâche « Combattre »

La sélection des actions conduit normalement à la sélection de l'action « Rejoindre(C) » qui permet de choisir un comportement de compromis entre l'attaque et l'évitement de B même si cette action est considérée comme moins prioritaire par chacun des deux comportements pris séparément.

Ce choix doit normalement conduire par la suite à la destruction de l'ennemi B ce qui entraînera une mise en veille de la motivation « Assurer sa sauvegarde » et de la mission « Combattre ennemis ».

2.5 Définition d’un nouvel outil pour la simulation

Comme on a pu le constater, la nouvelle approche apporte de nombreux avantages par rapport à l’approche traditionnelle des systèmes décisionnels.

Ces avantages peuvent désormais être exploités grâce à un outil développé et industrialisé par la société Mathématiques Appliquées SA (MASA)

Ce produit, qui s’inspire de la biologie, implémente un *système motivationnel*, c’est-à-dire un système capable de générer ses propres buts et d’en évaluer les intérêts respectifs. Un tel système est notamment capable de traiter plusieurs buts simultanément, de décomposer chacun de ces buts en sous-buts successifs et de combiner l’intérêt des alternatives concurrentes pour choisir la meilleure séquence d’actions possible. Ce faisant, elle résout le double problème de la *génération de buts* et de la *sélection de l’action* - ce qui la conduit à montrer, contrairement à une approche plus traditionnelle, une autonomie, des capacités d’adaptation et des comportements naturels qui rendent ses interactions éventuelles avec un humain très attractives.

3. La plate-forme de simulation MASA

Plusieurs applications industrielles ont déjà été réalisées par MASA en utilisant la nouvelle approche décrite plus haut :

- ***La formation*** : Développement d’une « Plate-forme de formation au management » - Manager’s Studio - réalisée pour la CEGOS,
- ***Le jeu*** : Production et développement du wargame temps réel « Conflict Zone » édité par UbiSoft,
- ***La simulation*** : Réalisation d’une étude pour le DGA / STTC « MCH : Etude d’évaluation d’un outil de modélisation du comportement humain ».

Pour chacune de ces applications, une couche métier a été réalisée et intégrée à une plate-forme de développement particulière.

Les paragraphes suivants présentent la plate-forme de simulation MASA qui a été utilisée pour réaliser l’étude MCH.

3.1 Présentation générale de l’étude MCH

L’objectif de l’étude MCH était l’évaluation d’un outil issu de la nouvelle approche « située » pour la modélisation et la simulation de forces aux niveaux unité élémentaire et section à des fins d’entraînement et/ou d’étude.

3.1.1 Description du scénario d’évaluation

Pour réaliser l’évaluation de l’outil, un scénario de type terrestre à trois niveaux tactiques (sous-groupement, peloton, groupe) a été défini et modélisé.

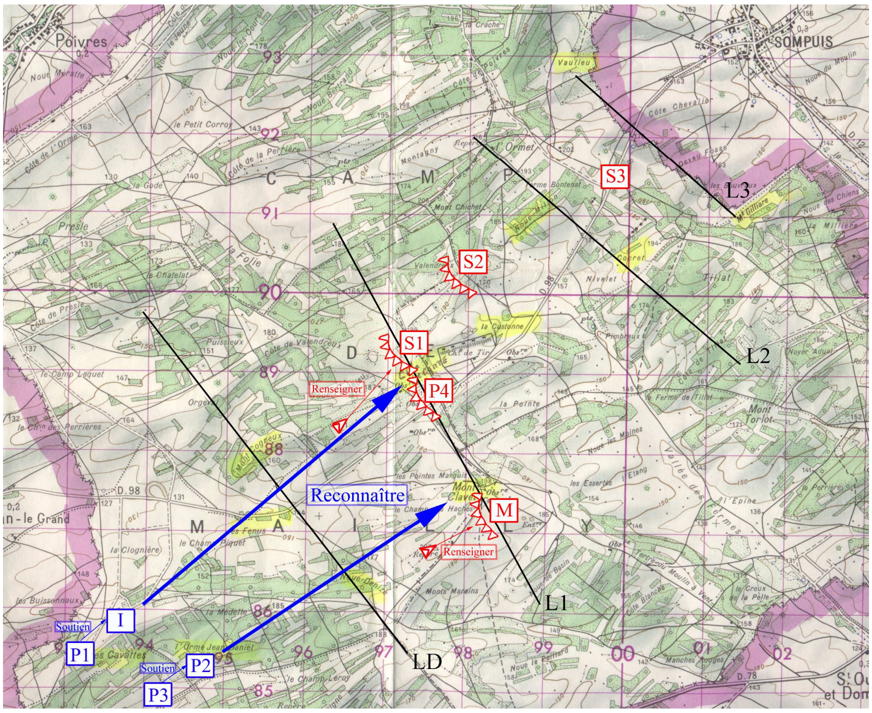

Figure 6 : Positions initiales des pelotons et sections du scénario modélisé sur le terrain de Mailly.

Le scénario confronte un sous-groupement blindé avec un sous-groupement mécanisé sur une bande de 10 Km sur 5 Km dans le camp d'entraînement de Mailly.

Le sous-groupement blindé est composé de :

- 3 pelotons blindés (P1, P2, P3), c'est-à-dire 12 chars AMX Leclerc,
- 1 section d'infanterie mécanisée (I), c'est-à-dire 4 AMX 10P et 39 soldats,
- 1 batterie d'artillerie de 8 pièces.

Le sous-groupement mécanisé est composé de :

- 3 sections d'infanterie mécanisée (S1, S2, S3), c'est-à-dire 12 BMP et 108 soldats,
- 1 peloton blindé (P4), c'est-à-dire 4 chars T80,
- 1 section Milan (M),
- 1 batterie d'artillerie de 8 pièces.

L'objectif du sous-groupement blindé est de s'emparer de la ligne [Vaulieu, Mt Gilliare] que doit défendre le sous-groupe mécanisé (Figure 6).

PHASES DU SCENARIO INITIAL	
Missions du sous-groupement blindé	**Missions du sous-groupement mécanisé**
Reconnaître	Préparer la défense
Fixer puis réduire les poches de résistance isolées	Porter un coup d'arrêt à la progression ennemie
Attaquer en profondeur	Freiner l'ennemi
Conquérir la seconde ligne	Défendre la seconde ligne

Tableau 1. Résumé des phases du scénario initial

Le scénario s'articule en quatre phases successives dont l'exécution est préfixée (Tableau 1).

Il faut noter que ce scénario est issu d'un exercice d'entraînement qui a été réalisé en réel dans le camp de Mailly, ce qui a facilité le travail d'évaluation de la modélisation.

3.1.2 Description de la modélisation

Pendant le déroulement de l'étude, le terrain de Mailly a été modélisé à partir de trois couches de données numériques (Figure 7) :

- ➢ Altimétrie,
- ➢ Densité de forêts,
- ➢ Axes de communications.

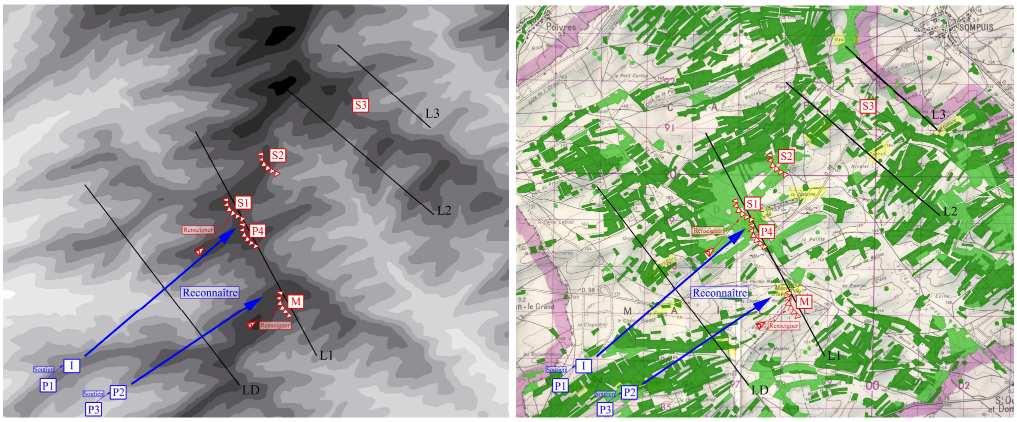

Figure 7 : Données numériques d'altimétrie (à gauche) et de planimétrie (à droite) permettant de modéliser le terrain.

Ce scénario a nécessité la modélisation de 108 pions représentant un total de 241 combattants. Le niveau des pions élémentaires a été fixé au niveau du char et de trinôme de fantassins.

La prise de décision a été modélisée sur 4 niveaux (Figure 8) :

- Capitaine,
- Chef de peloton ou section,
- Chef de groupe ou de char,
- Trinôme de fantassins.

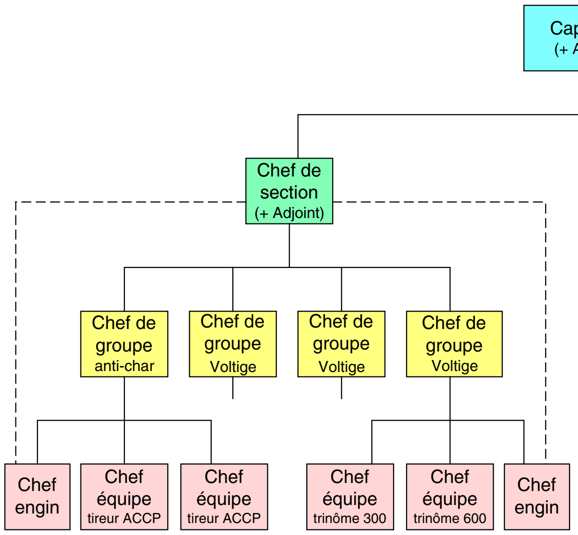

Figure 8 : Données numériques d'altimétrie (à gauche) et de planimétrie (à droite) permettant de modéliser le terrain.

Entre chacun de ces niveaux, les automates de commandement ont été dotés des capacités leur permettant de décomposer leurs missions pour donner des ordres à des subordonnées. Inversement, les unités subordonnés ont été dotées des capacités de traitement des ordres qu'elles reçoivent avec la possibilité d'effectuer des compte-rendus vers leur supérieur.

La phase d'évaluation de l'étude a démontré les potentialités de l'outil de MASA dans le cadre de la simulation militaire.

En particulier, les opérationnels qui ont participé à l'évaluation ont particulièrement souligné les capacités d'automatisation des entités simulées et la facilité d'intégration de nouveaux modèles de doctrines, en particulier de doctrines non-conventionnelles.

L'étude a également permis de valider l'approche itérative du recueil d'expertise décisionnelle qui sera décrite plus loin.

3.2 Architecture logicielle de la plate-forme de simulation

3.2.1 Description générale

L'architecture logicielle (Figure 9) de la plate-forme de simulation a été développée par MASA pour intégrer dans un seul outil l'ensemble des fonctionnalités nécessaires à la création d'une simulation opérationnelle telle que celle qui a été mise en œuvre pour l'étude MCH.

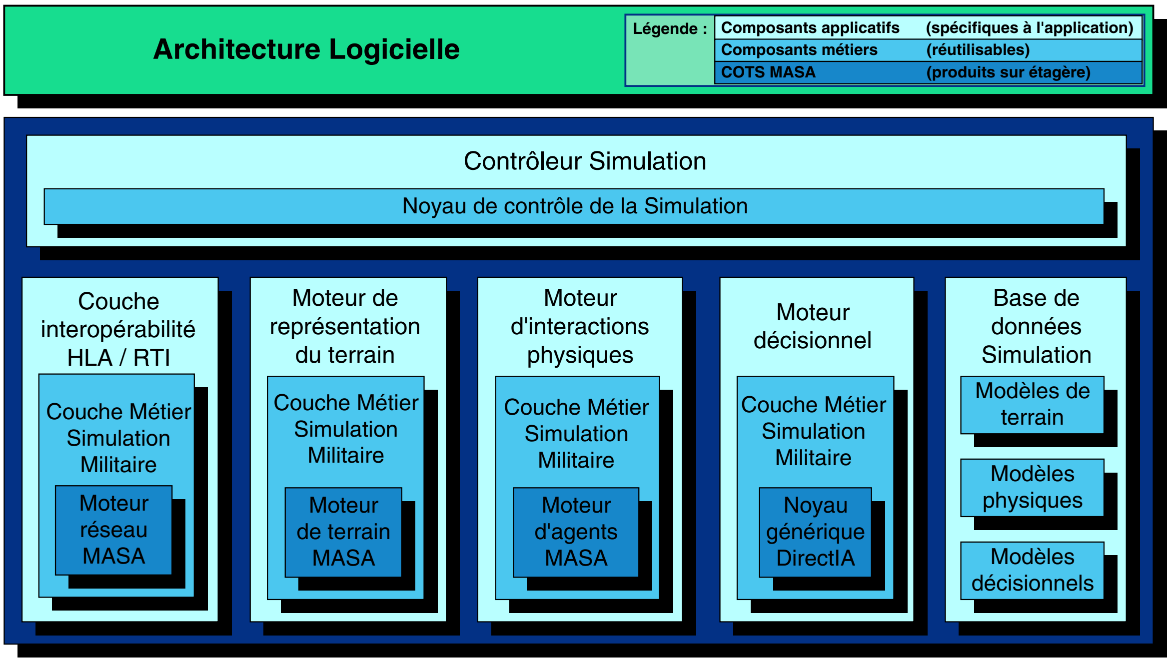

Figure 9 : Architecture logicielle de la plate-forme de simulation

Cette plate-forme utilise quatre moteurs génériques (moteur réseau, moteur graphique, moteur d'agents et noyau DirectIA) sur lesquels se greffe une couche métier spécialisée pour la simulation militaire.

Les quatre moteurs génériques ont été testés et validés dans le cadre de projets touchant à des métiers très différents (simulation militaire, formation au management, pédagogie, jeux vidéos, robotique, etc.).

Pour chacun de ces moteurs, une couche spécifique au métier « simulation militaire » a été développée ce qui permet de maîtriser l'expérience acquise dans le domaine de la Simulation militaire en la factorisant dans différents composants réutilisables.

Cette couche métier inclut un noyau de contrôle de la simulation qui permet de faire fonctionner ensemble les différents moteurs. Elle comprend aussi un formalisme générale pour décrire sous la forme de fichiers de données les modèles de terrain, les modèles physiques et les modèles décisionnels.

Au dessus de la couche métier peut être développée la couche logicielle spécifique à chaque application.

3.2.2 Description des composants génériques

La plate-forme comprend quatre moteurs génériques déjà sur étagère :

- ***Le moteur réseau MASA*** : comprend l'ensemble des procédures génériques d'interopérabilité permettant à des composants logiciels de s'interfacer et de communiquer entre eux lorsqu'ils sont situés sur des machines différentes.

- ***Le moteur de terrain MASA*** : contient l'ensemble des primitives permettant de construire une représentation interne en 3 dimensions de l'environnement physique. Ce moteur contient aussi les mécanismes élémentaires d'interactions entre l'environnement et les objets qu'il contient.
- ***Le moteur d'agents MASA*** : permet de modéliser les objets physiques utilisés dans la simulation et en particulier les pions de la simulation. Ce moteur contient également les mécanismes élémentaires d'interactions physiques entre objets de la simulation.
- ***Le noyau générique DirectIA*** : est un moteur générique de sélection de l'action basé sur l'approche située. Utilisé en combinaison avec le moteur d'agents MASA, DirectIA permet de sélectionner les comportements permettant d'animer des pions de la simulation.

3.2.3 La couche métier spécifique

La couche métier comprend l'ensemble des composants spécifiques au métier de la « Simulation militaire » que l'on peut conserver d'une application à une autre à des fins de réutilisation.

Cette couche métier évolue à chaque nouvelle application en intégrant à chaque fois des composants suffisamment généraux pour pouvoir être utilisés dans les applications ultérieures.

- ***La couche métier du moteur de terrain*** a été développée pour permettre la génération automatique de terrains de taille et de forme quelconque à partir de données numériques. Grâce à son interconnexion avec la couche métier du moteur d'agents, ce moteur permet de donner aux pions d'une simulation militaire un mécanisme d'intervisibilité particulièrement optimisé.
- ***La couche métier du moteur d'agents MASA*** a été développée pour animer les entités physiques des pions d'une simulation militaire. C'est en particulier ce moteur qui gère les capacités d'agrégation/désagrégation des pions. Grâce à son interconnexion avec la couche métier du moteur de terrain, ce moteur permet de gérer les interactions entre les pions de la simulation en réalisant notamment tous les calculs d'attrition.
- ***La couche métier du moteur réseau*** met en œuvre les interfaces HLA permettant de faire communiquer la plate-forme de simulation avec d'autres simulations. Cette couche est encore en cours de développement.
- ***La couche métier de DirectIA*** correspond à la spécialisation de DirectIA pour la problématique de la simulation opérationnelle. Associée aux couches métier des trois autres moteurs, elle permet le contrôle des agents décisionnel de la simulation en leur associant à chacun une doctrine définie et une place dans un ODB. Cette couche métier regroupe l'ensemble des procédures générales permettant à l'agent de percevoir sa situation sur le terrain de recevoir des ordres ou des comptes-rendus ou d'en envoyer, de gérer la coordination d'autres pions ou de sélectionner un comportement opérationnel conforme à la doctrine.
- ***Le formalisme des modèles de la simulation*** (modèles de terrain, modèles physiques, modèles décisionnels) fait partie de la couche métier. Ces modèles peuvent être « chargés » par les trois moteurs de la couche métier pour modéliser un terrain particulier sur lequel sont animés des pions dont le comportement physique de même que les capacités de décision peuvent être paramétrés.
- ***Le noyau de contrôle de la simulation*** qui fait aussi partie de la couche métier a pour rôle principal de coordonner l'action conjuguée des trois moteurs de la couche métier et leur fréquence d'appel. Il contrôle également l'initialisation des moteurs à partir des fichiers de description des modèles.

3.2.4 Propriétés de la couche métier

La couche métier « Simulation militaire » de MASA a été développée de manière à pouvoir illustrer notamment les propriétés suivantes :

Utilisation d'un langage de script directement compréhensible par les opérationnels,

Grande modularité du développement des modules de comportement

Incrémentalité du processus de recueil et de modélisation de l'expertise opérationnelle.

➢ Ces trois propriétés sont illustrées dans les paragraphes suivants.

Un langage de script compréhensible par les opérationnels

L'insertion des éléments de doctrine dans DirectIA se fait au moyen de fichiers de script dont le langage se veut le plus proche possible du langage utilisé par les opérationnels eux-mêmes. Cette propriété donne la possibilité aux opérationnels de participer de manière active à la modélisation des comportements.

La Figure 10 donne un exemple (simplifié pour la présentation) des scripts utilisés pour modéliser la mission « Attaquer » d'un escadron blindé.

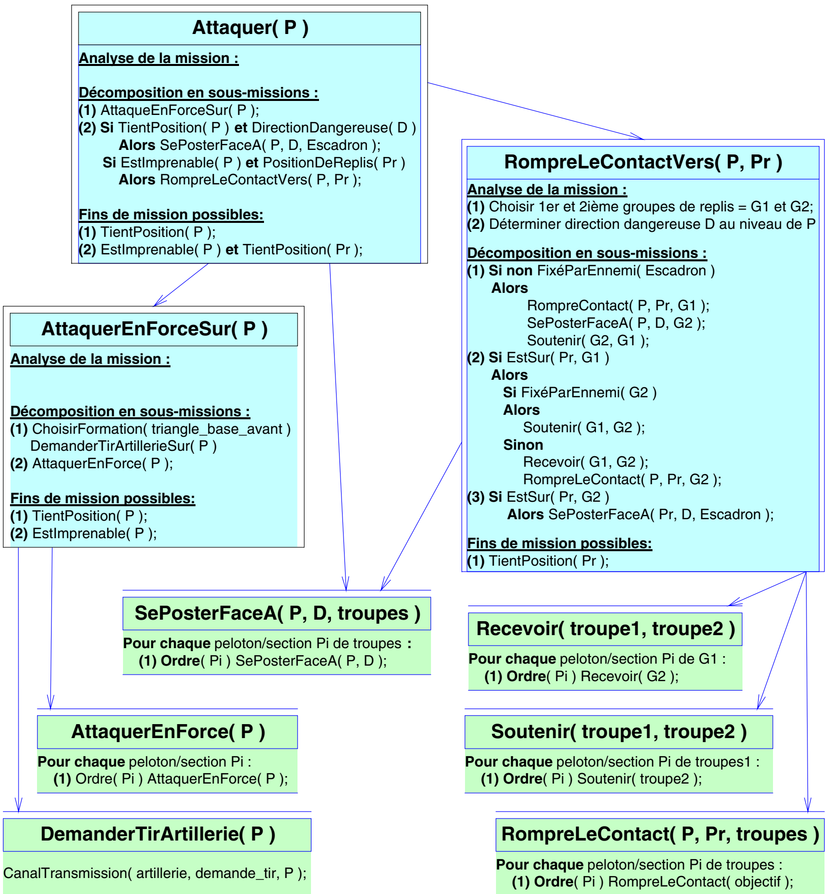

Figure 10 : Graphe de comportement modélisant la mission «Attaquer » d'un escadron blindé

Outre la simplicité du langage utilisé pour modéliser une mission, on peut noter plusieurs propriétés intéressantes de cette méthodologie :

➢ ***La généricité*** : Chaque module utilise des variables qui peuvent être renseignées pendant le déroulement de la simulation.

➢ ***La réutilisabilité*** : Un module déjà développé peut être utilisé dans plusieurs contextes différents (c'est le cas par exemple du module « SePosterFaceA ») .

➢ ***La possibilité de modéliser un mode d'action par une séquence*** : Chaque mission peut être décrite par une séquence de tâches à réaliser (ici une séquence de deux groupes d'actions (1) et (2)).

➢ ***Le parallélisme entre les modes d'actions*** : Les modes d'action peuvent être mis en concurrence à chaque étape de la séquence des tâches qui caractérise la mission. Ici, deux modes d'action sont proposés lors de l'étape (2) pour terminer la mission.

Une modélisation modulaire des missions

La Figure 10 montre aussi la grande modularité de la méthodologie de modélisation. Ainsi, le module « RompreLeContact » n'a pas été développé uniquement pour modéliser le comportement « Attaquer » : c'est un module générique qui peut être activé pour modéliser d'autres missions (par exemple, Freiner).

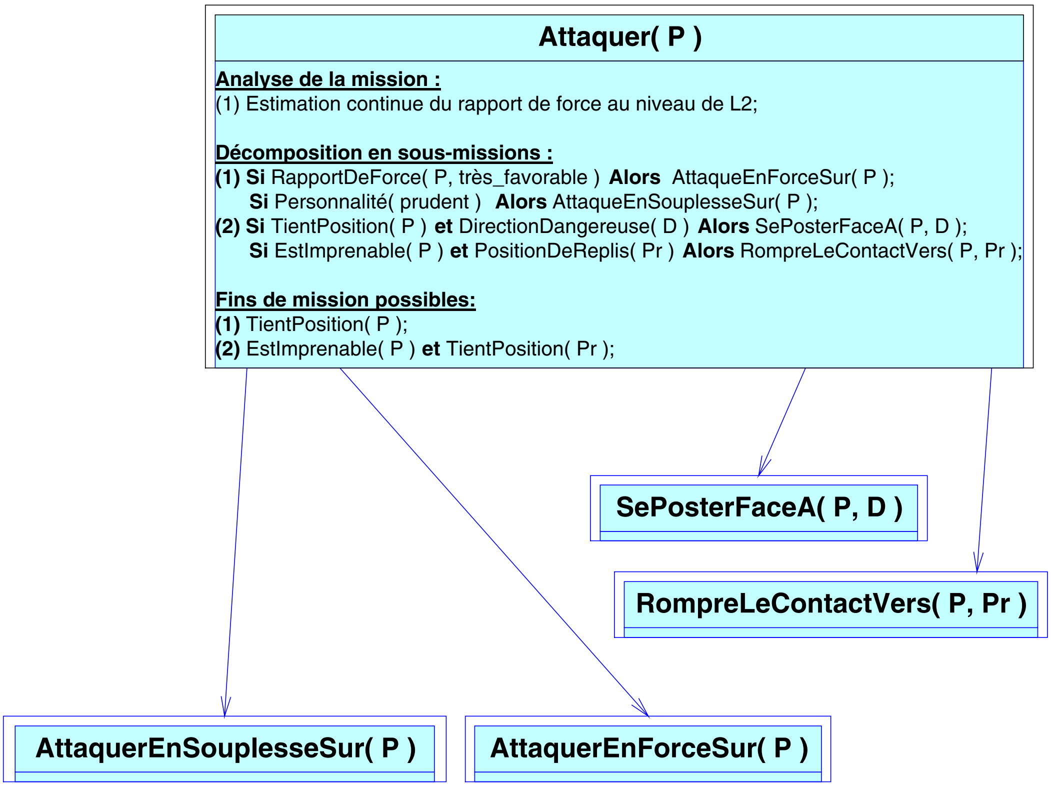

Figure 11 : Exemple d'ajout d'un mode d'action dans la mission «Attaquer » du graphe de la Figure 10.

La Figure 11 présente un autre exemple de cette fonctionnalité. Dans cette exemple, on a ajouté un mode d'action supplémentaire à la mission « Attaquer » avec le comportement « AttaquerEnSouplesse ».

Il faut noter que l'intégration d'un nouveau mode se fait au moyen d'une seule règle de décision une fois que le comportement « AttaquerEnSouplesse » a été modélisé.

Un processus incrémental de recueil et de modélisation de l'expertise opérationnelle

La modélisation de la doctrine dans la couche métier de DirectIA suit une procédure itérative dont la Figure 12 résume le déroulement.

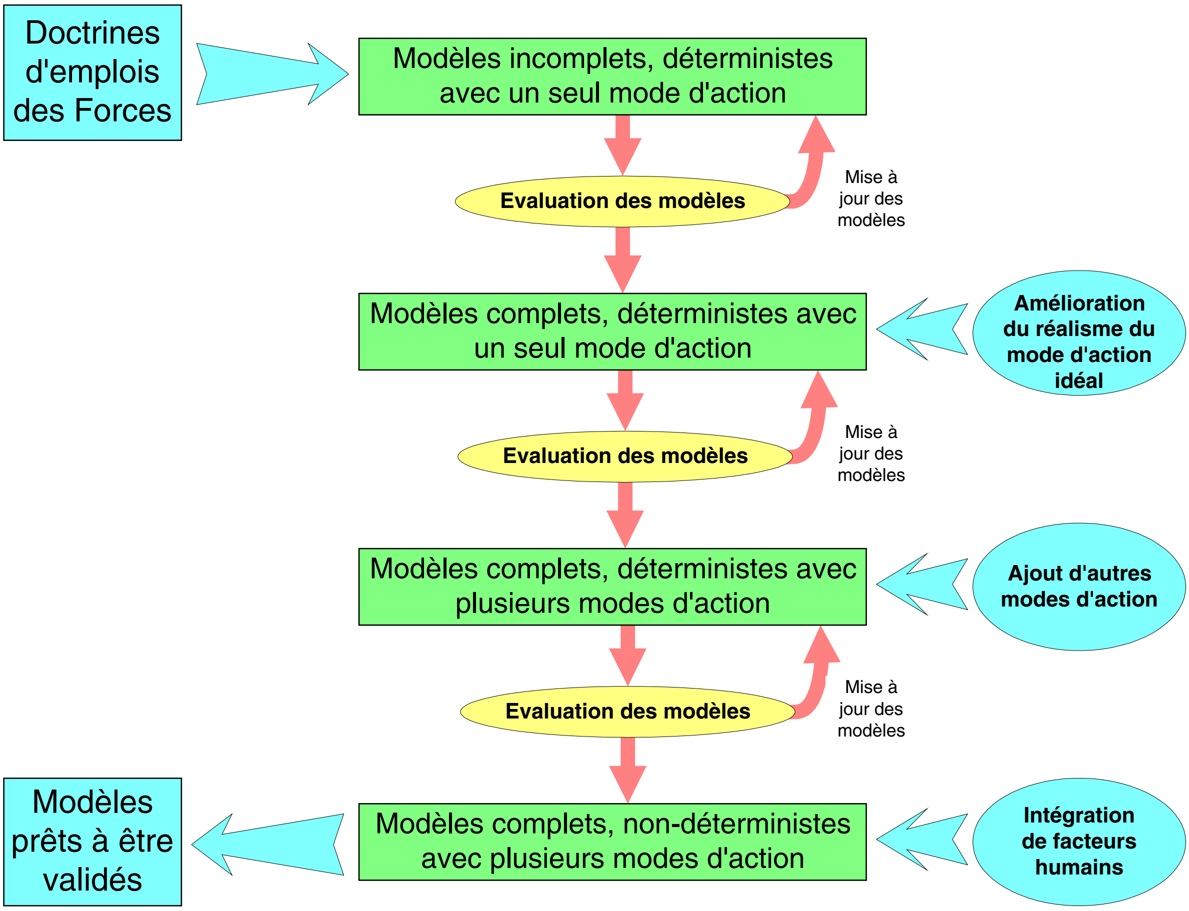

Figure 12 : Processus de recueil et de modélisation de l'expertise opérationnelle

Cette procédure se décompose en trois phases :

- ***Phase 1*** : Amélioration du réalisme du mode d'action principal,
- ***Phase 2*** : Ajout et test des autres modes d'action,

Phase 3 : Intégration (optionnelle) des facteurs humains dans le choix du mode d'action.

Chacune de ces trois phases donne lieu à des évaluations intermédiaires et à une mise à jour progressive des modèles. Chaque mise à jour des modèles consiste principalement à modifier les fichiers de scripts qui sont utilisés par DirectIA.

Nous avons pu constater dans le cadre du projet MCH la richesse de l'expertise opérationnelle par rapport aux documents papier qui nous avaient été remis et qui ont permis d'initier la modélisation.

Ce projet a permis de valider notre approche itérative du recueil d'expertise décisionnelle. Il apparaît en effet essentiel de confronter les experts opérationnels à la simulation pour ajouter les règles décisionnelles permettant d'améliorer progressivement le rendu opérationnel du comportement des unités.

3.3 Fonctionnalités de la plate-forme de Simulation

Les paragraphes suivants décrivent les fonctionnalités de la plate-forme en les comparant avec celles des systèmes de simulation plus traditionnels.

3.3.1 Représentation des pions

Contrairement aux systèmes de simulation traditionnels, un pion est modélisé non seulement par une entité physique mais également par un agent décisionnel, ces deux composants du pion restant très interconnectés (Figure 13) :

- ***L'entité physique*** : représente le « corps » du pion. Elle définit ses caractéristiques physiques (ses capacités de perception, de feu, de blindage, etc.).
- ***L'agent décisionnel*** : représente la « tête » du pion. Il définit sa capacité à raisonner pour exécuter un ordre qu'il a reçu en utilisant au mieux la doctrine qui le caractérise, les connaissances qu'il possède et sa perception de la situation sur le terrain.

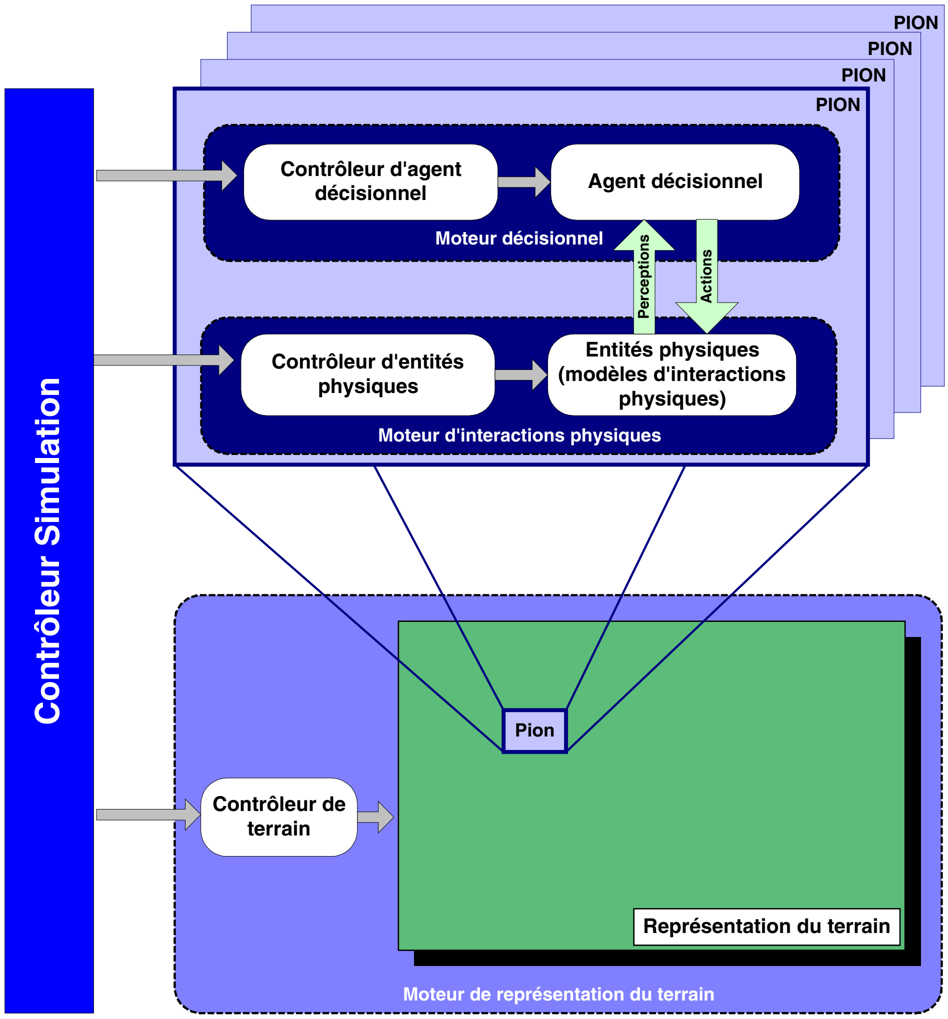

Figure 13 : Interfaçage entre les pions et le terrain

Même si l'objet pion existe dans le système et peut être indexé globalement, c'est le moteur d'interactions physiques qui contrôle l'ensemble des entités physiques de la simulation et c'est le moteur décisionnel qui a le contrôle sur chaque agent décisionnel.

3.3.2 Interopérabilité entre les différents moteurs

La plate-forme de simulation est un système de simulation intégré dont l'architecture des composants internes suit des principes d'interopérabilité proches du format HLA-RTI.

L'ensemble de ces interactions est arbitré par le contrôleur de simulation en particulier pour la gestion du temps (Figure 14). Celui-ci traite aussi les communications entre les différents moteurs et leur interfaçage avec l'extérieur de la simulation (par exemple des postes d'animation).

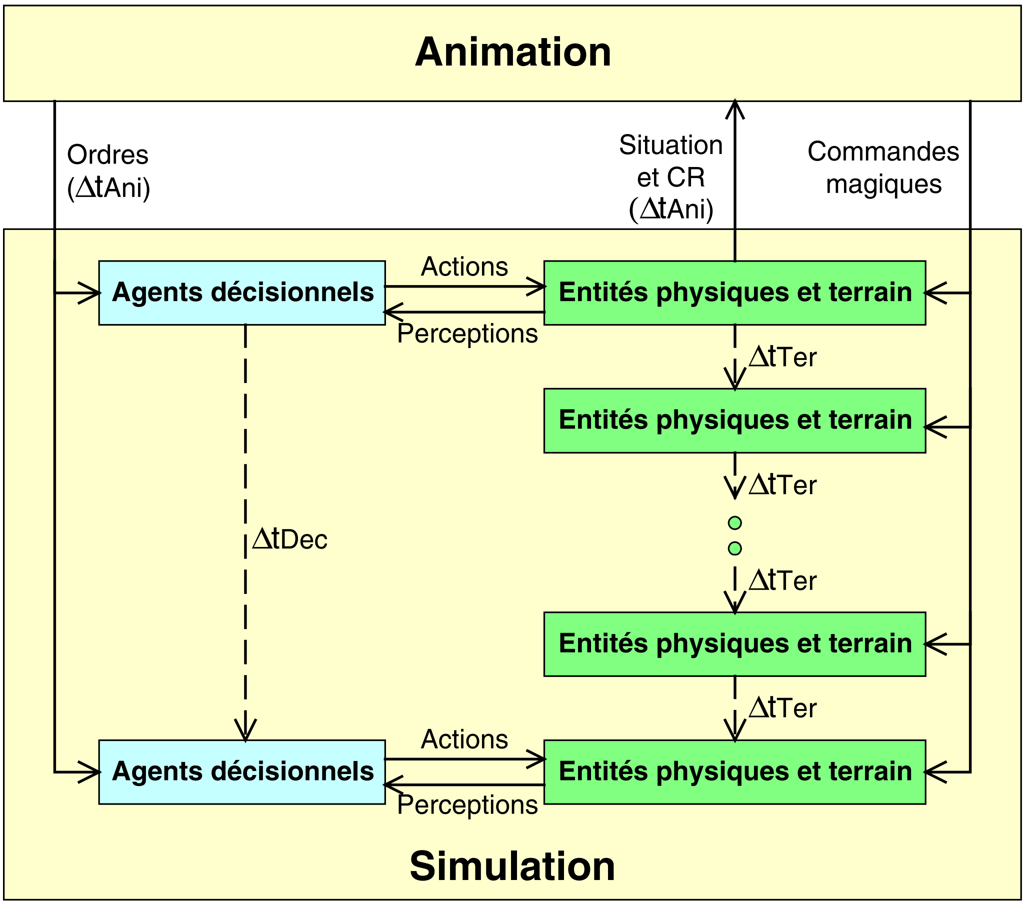

Figure 14 : Contrôle des interactions entre les moteurs

Il faut noter que les différents pas de temps interne à la simulation peuvent être variables et asynchrones :

- ***Variables*** : parce que toutes les entités n'ont pas besoin d'être remises à jour avec la même fréquence (par exemple, un pion de combat sera remis à jour plus souvent qu'un pion logistique).
- ***Asynchrones*** : parce que la remise à jour des entités peut être accélérée à l'arrivée de nouveaux événements (par exemple, le pas de temps d'un pion qui se fait attaquer alors qu'il était en zone de sûreté pourra être abaissé).

3.3.3 Capacités de distribution de la plate-forme

Une des caractéristiques intéressantes de la plate-forme est sa capacité à être distribuée sur un réseau de machines. Cette capacité provient des fonctionnalités d'interopérabilité de la plate-forme qui permettent d'échanger facilement des objets entre deux instanciations placées sur des machines différentes.

La Figure 15 illustre cette propriété de distribution. Sur cet exemple, les pions d'une simulation ont été distribués sur un hypercluster de simulation, c'est-à-dire sur un ensemble de machines connectées en réseau.

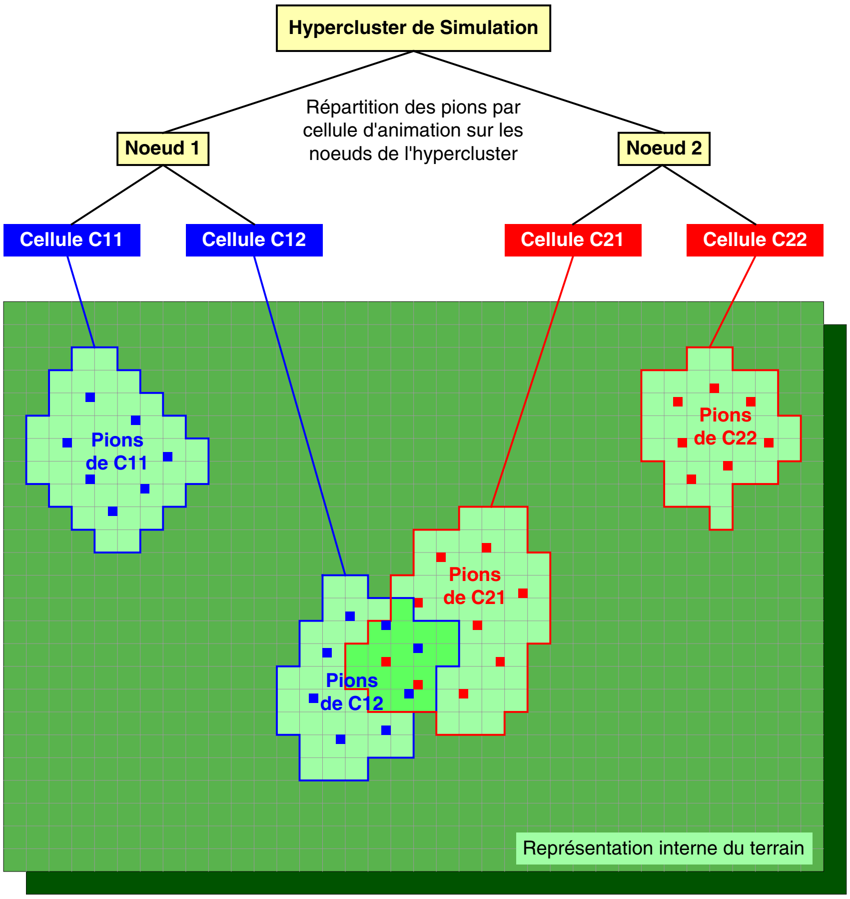

Figure 15 : Capacités de distribution de la plate-forme

Chaque nœud de ce réseau, c'est-à-dire chaque machine, a la responsabilité de gérer les moteurs physiques et décisionnels de l'ensemble des pions de plusieurs cellules d'animation (par exemple 2 sur la figure).

Il peut aussi gérer une représentation partielle (type, position, attrition, etc.) d'autres pions qui sont modélisés au niveau d'un autre nœud de l'hypercluster.

Chaque nœud contient une représentation complète du terrain initial, dénudée de tous ces pions. Cependant, pendant le déroulement de la simulation, chaque nœud (c'est-à-dire chaque machine) gère la représentation de la partie du terrain qui est utilisée par les entités modélisées au niveau de ce nœud
Ainsi sur la figure, seules les deux zones de terrain de couleur claire associées aux cellules C1 et C2 sont traitées au niveau du nœud 1 de l'hypercluster.

3.3.4 Interopérabilité avec d'autres simulateurs

La capacité à être interopérable avec d'autres simulateurs est une des caractéristiques essentielles de la plate-forme de simulation. La mise en conformité HLA-RTI de la plate-forme est donc nécessaire.

Comme cela a été dit plus haut, les concepts architecturaux de la plate-forme sont proches de ceux de HLA : interaction via un contrôleur spécialisé, contrôle distribué et hiérarchisé. La connexion à un RTI ajoute un étage supplémentaire à celui des moteurs et du superviseur.

Cette compatibilité conceptuelle profonde assure que la plate-forme de simulation tirera réellement profit de sa coopération avec d'autres simulateurs, sans rencontrer des difficultés de mise au point de la fédération.

A cette fin, la plate-forme répond aux exigences HLA en proposant les interfaces d'entrée / sortie nécessaires à l'enregistrement d'un SOM (Simulation Object Model) lorsque l'on voudra faire participer le système à une fédération de simulateurs.

Suivant les besoins de la fédération, il sera alors possible d'utiliser tout ou partie des éléments interopérables de la plate-forme de simulation (données sur les entités physiques, sur les agents décisionnels, sur le terrain modélisé) pour construire le SOM. Au niveau « Architecture Logicielle », c'est le contrôleur simulation qui est chargé de réaliser l'interopérabilité avec d'autres simulateurs.

La Figure 16 explicite les mécanismes dont il faut doter la plate-forme pour qu'elle soit compatible HLA-RTI .

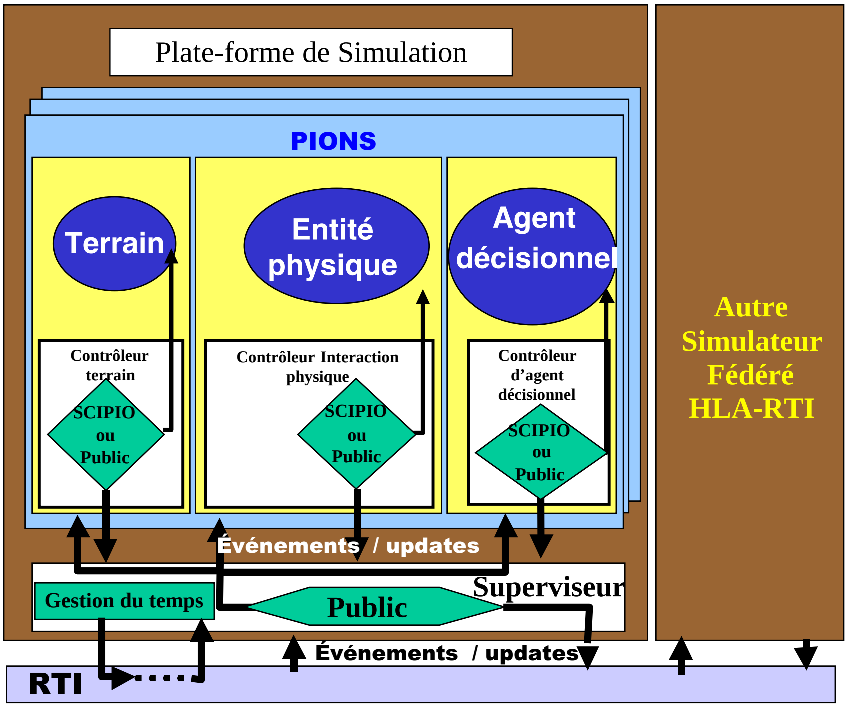

Figure 16 : Mise en conformité HLA-RTI de la plate-forme de Simulation

Les simulateurs fédérés HLA échangent des événements et des mises à jour (« updates ») relatifs aux objets qu'ils publient (« publish ») et auxquels ils s'abonnent (« subscribe »).

En résumé, il ne s'agit pas de l'écriture d'un module supplémentaire qui serait un adaptateur HLA-RTI. Il s'agit de modifications à apporter à divers modules existants de la plate-forme, pour qu'ils étendent leur mécanisme de prise en compte des interactions et de gestion du temps à un ensemble de moteurs, représenté par la fédération.

4. Conclusions et perspectives

Cet article a décrit une nouvelle approche, dite « située » de la prise de décision dans les simulations opérationnelles, permettant notamment d'associer aux agents de véritables capacités d'automatisation.

Du point de vue logiciel, l'utilisation d'une plate-forme de simulation intégrée, interopérable et évolutive offre la capacité de capitaliser l'expérience acquise de projet en projet.

L'utilisation d'un langage de script proche du langage naturel et facilement compréhensible par les opérationnels offre une grande souplesse de modélisation et de modification des modèles.

Le recueil d'expertise est effectué de manière incrémentale, avec une grande visibilité pour les utilisateurs finaux, qui peuvent interagir à tout moment pour modifier chaque élément de doctrine spécifique. Cela constitue une véritable innovation en regard des techniques classiques de modélisation, très statiques, qui nécessitent un réglage fin, inaccessible en cours de développement.

Contrairement aux approches traditionnelles de la prise de décision dans la simulation, le formalisme de description des doctrines ne s'intéresse pas aux situations que l'entité peut rencontrer mais aux comportements qu'elle peut mettre en œuvre. La nouvelle approche est capable de **modéliser des modes d'actions très complexes en utilisant un nombre réduit de règles de décision**.

Ce formalisme permet véritablement d'améliorer le niveau de modélisation des pions par rapport à ce que l'on rencontre dans les simulations traditionnelles :

- ***Augmentation de l'automatisme des pions*** qui disposent de capacités décisionnelles évoluées.

Délégation des ordres à des automates de commandement capables de commander des pions et d'autres automates de commandement.

La nouvelle approche « située » de la prise de décision s'avère donc particulièrement adaptée pour modéliser avec suffisamment de finesse des comportements et des missions hors de portée des approches traditionnelles :

Modélisation des civils (populations, médias, etc.),

Modélisation de doctrines non conventionnelles (milices, terroristes, etc.),

- Modélisation des nouveaux éléments de doctrine associés aux opérations de projection de forces.

L'utilisation de ces nouveaux modèles de comportement correspond ainsi tout particulièrement aux besoins émergents de la simulation (projection de forces, guérilla urbaine, combats asymétriques, etc.).

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SIMTECH 2007 … and Beyond

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Abstract

During the course of over a decade, the Military Operations Research Society (MORS) has sponsored a sequence of workshops on the subject of simulation technology. The broad objectives of these workshops were to identify and prioritze the needs of the users of military modeling and simulation (M&S), assess the probable evolution of M&S technology, and to identify potential user shortfalls and opportunities to ameliorate them. This paper summarizes the major findings and recommendations of the last of these workshops, Simulation Technology (SIMTECH) 2007. It focuses on the M&S needs for three major user groups: analysts, acquirers of systems, and educators and trainers. For each of these user groups, a vision is articulated and recommendations are posed to realize those visions. The paper concludes with a brief look at promising new M&S initiatives in each of these functional areas as well as major residual issues that confront the M&S community.

A. Context

Approximately a decade ago, the Military Operations Research Society (MORS) sponsored a series of three workshops under the rubric of Simulation Technology 1997 (SIMTECH 97). Those workshops focused on identifying and satisfying the simulation technology needs of the analyst in the late 1990s. Ultimately, that activity culminated with a set of findings and recommendations on four major themes: lifecycle management for Modeling and Simulation (M&S); a workstation for the analyst; dealing with “soft factors” (e.g., cognitive factors, performance modulators) in M&S; and responding to M&S’s needs for data. In 1997, several of the original organizers of SIMTECH 97 believed that it was an appropriate time to re-assess the results of the prior workshops and to look ten years into the future.

The overarching goal of this new series of workshops was to promote more effective dialogue between the M&S technology community and an expanded set of users of M&S: analysts, acquirers and educators and trainers.

Consistent with this goal, four subordinate objectives were identified:

- Review and assess the findings and recommendations from SIMTECH 97;
- Identify and prioritize the needs of the users of military M&S;
- Assess the probable evolution of M&S technology over the next decade; and,
- Identify potential user shortfalls and opportunities to ameliorate them.

Paper presented at the RTO NMSG Conference on “Future Modelling and Simulation Challenges”, held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

To satisfy these goals and objectives, two workshops were convened. The first workshop was conducted at GRCI, Tysons Corner, VA, on 16-18 December 1997. It began with retrospective assessments by working groups organized around the four major themes that were addressed in SIMTECH 97. Drawing on the lessons learned from the retrospective assessments, the participants were reorganized into parallel clusters of M&S users and technologists. The users identified and prioritized the M&S needs of analysts, acquirers and educators and trainers. The technologists formulated a taxonomy for M&S technology and, within that context, forecast conservative and aggressive estimates for the state of M&S technology by 2007.

The second workshop was conducted at the Institute for Defense Analyses (IDA), Alexandria, VA, on 18-20 August 1998. The workshop began by having hybrid working groups of M&S users and technologists refine their products from Workshop I. Subsequently, after a sequence of M&S technology presentations, these hybrid working groups identified a comprehensive set of shortfalls (subsuming policy, management and technology) and formulated recommendations to ameliorate them.

This paper summarizes the major findings and recommendations of SIMTECH 2007. In addition, it looks beyond those results to identify promising new initiatives and major residual issues that have emerged since the completion of SIMTECH 2007.

B. Key Products

This section of the paper introduces a technology taxonomy that was developed during SIMTECH 2007 and summarizes the results of the three functional assessments.

B.1 Technology Taxonomy and Assessment. As a basis for simulation technology projections, a taxonomy was developed that can be depicted as a jig saw puzzle with four interlinking pieces (see Figure 1):

- modeling methodology (i.e., the theories, processes, algorithms and information that support the conceptualization of a model);
- development methodology (i.e., the tools, techniques and software used in architecting, designing and implementing a model);
- computation and communications technology (i.e., the platform the M&S application is hosted on, how it connects to other M&S applications, and how M&S application developers and users connect to one another); and
- data and information technology (i.e., the processes and tools needed to acquire and transform data and information).

For each of these areas, technology projections were made under conservative assumptions (e.g., continuation of current investment priorities) and aggressive assumptions (e.g., substantial increase in priority with the subsequent likelihood of a breakthrough). The results of those technology projections are presented later in the paper.

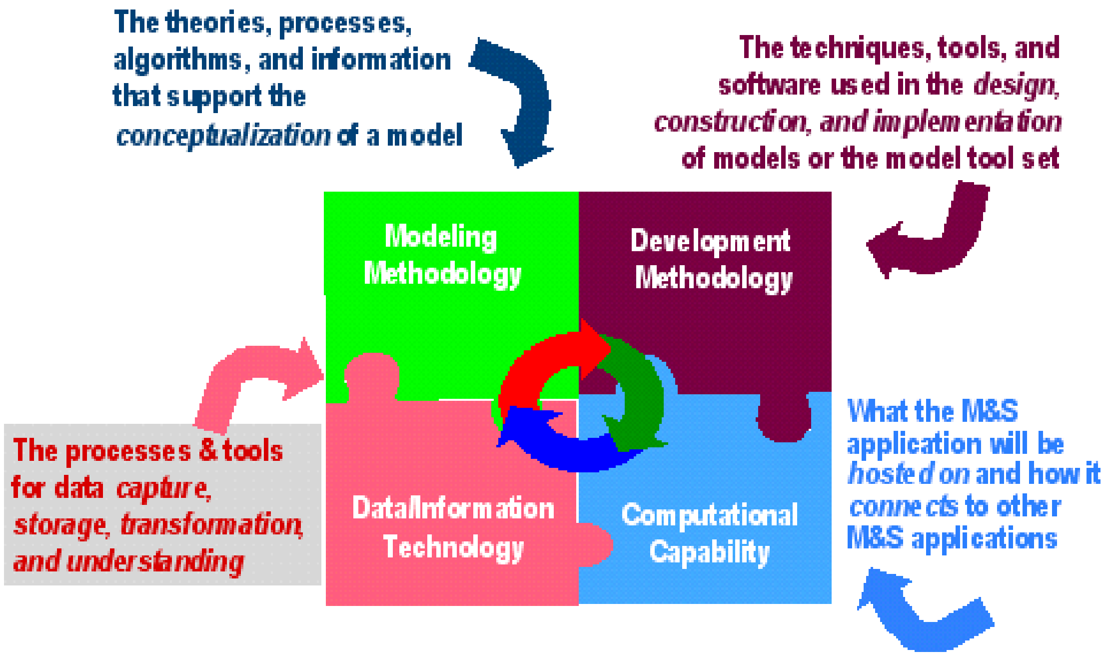

Figure 1: SIMTECH 2007 Technology Taxonomy

As a baseline, the Technology Working Group characterized the state of simulation technology as of 1998. They concluded the following. First, in the area of modeling methodology many major simulations are too hard to use and their results are too hard to understand. Second, it was observed that the acquisition of simulations is often equivalent to the acquisition of large, complex software systems. Currently, the scale of most contemporary military simulation systems is such that the community can not reliably acquire them within cost and schedule goals. Third, it was concluded that computational capability was not a major limiting factor for the bulk of simulation needs. Finally, it was observed that data presents a very difficult, pervasive problem, both in its acquisition and its transformation into products needed by the M&S community.

B. 2 Functional Area Assessments. For the functional areas of analysis, acquisition and education and training, top-down assessments were performed. These include an articulation of a vision for the functional area; an identification of associated needs (in policy, management and technology); a characterization of perceived shortfalls (e.g., an identification of cases where technology needs exceeded aggressive projections (assessed as “red”) and cases where technology needs fell between conservative and aggressive projections (assessed as “amber”)); a set of recommendations to ameliorate perceived shortfalls; and sensitivity assessments to establish the robustness of the recommendations.

B.2.1 Analysis. The Analysis Working Group defined a vision describing the following operating circumstances of the analyst in 2007. First, multidimensional demands of joint, coalition and international operations will best be met by conducting analysis via teams that mix the right skills and experience to answer pertinent issues. Such teams will match analysts with a broad range of other professionals, including specially trained simulators and communicators. Second, in ten years, the analyst will find it easy and normal to work in a distributed analysis environment in direct support of the commanders and decision makers at all levels, wherever they are. Finally, there will be a strong command and control component to analytic issues, which the simulations of the day will be better prepared to address. The growth of a new generation of analytic tools, decision aids, and data bases will allow the analyst to focus first on the question of interest and then settle on the appropriate tools for the job.

The Analysis Working Group also proposed recommendations in the areas of an analyst tool chest, procedures, data, and people. A concise summary of those recommendations follows.

• Tool Chest. The Analysis Working Group recommended that a community-wide effort be initiated to create an Analyst Tool Chest. There are three major components of this proposed effort. First, work should be undertaken to create and sustain M&S that treat command and control explicitly to deal with key operations of interest. Consistent with emerging issues of interest, two classes of operations were emphasized. First there is a need for tools to analyze the missions associated with operations other than war (OOTW). This includes humanitarian assistance, disaster relief, and peace operations. Second, new concepts of warfare are emerging for which M&S are needed. This includes network centric warfare, information warfare, small unit operations (particularly in complex terrain), non-lethal weapons, and counter-terrorism. Next, the Working Group recommended that existing tools should be augmented with the latest conceptual thinking and techniques. These include advances in complexity and chaos theory and new tools such as agent based models to study emergent behavior and genetic algorithms to derive optimal solutions to complex, non-linear problems. Finally, the Working Group recommended that new features be incorporated into our tools to make them more flexible and easier to use. Among the features identified were intelligent agents to “bookmark” key events in a simulation to facilitate “what if…” analyses, enhanced visualization capabilities to facilitate communications with decision makers, and data mining and knowledge discovery tools to deal with the immense loads of data generated in simulations and experiments.

• Procedures. In the area of procedures it was recommended that analysts be encouraged to explore “study space” fully. This reflected the concern that many studies artificially limited their scope to conditions that did not reflect the full range of risks and uncertainties that were of interest to the decision maker. Second, it was recommended that advanced warfighting experiments should be supported by an analytic process to derive valid conclusions and usable data. This process includes both a solid structure to define the experiments and analytic procedures to extract valid insights from the volumes of data generated. Finally, in order to continue the advancement in analysis, it was important to establish a program of continued research that addresses both military phenomenology and scientific advancement. In particular, it was recommended that further effort be invested in pursuing and developing the “new sciences”(e.g., complexity, chaos theory) and teaching their theory and application to new practitioners.

• Data. In the area of data, it was recommended that a comprehensive process for data management be instituted. In addition, it was proposed that technologies be developed for data extraction and analysis of useful data from events (e.g., by employing intelligent agents) and information from data (e.g., by employing innovative visualization tools). In addition, to provide assistance to analysts in identifying and gaining access to verified, validated, and certified data, it is recommended that a “Help Desk” be established.

• People. In the area of people, it was recommended that a formal educational course be established that trains analysts in the techniques and processes involved in complex analysis. Moreover, since capabilities will continue to emerge and be refined, a continuing education process is recommended to keep analysts qualified in the latest techniques. In addition, it was recommended to develop educational approaches that highlight the ability to design a complex, high dimensionality analysis, to execute it in a distributed fashion, and to conduct a thorough analysis of the outputs. While the tools of experimental design, stochastic modeling, and computer science will fill much of the need, education and practice in a focused curriculum will result in a more responsive, innovative analysis.

B.2.2 Acquisition. The vision of the Acquisition Working Group is a new acquisition paradigm that yields substantial reductions in time, resources, risk, and total ownership costs throughout the life cycle process, while simultaneously increasing the system's quality, military worth, and supportability.

In order to achieve those benefits, it is perceived that the intelligent use of simulations is the critical enabler. These simulations must be robust, used collaboratively by all of the stakeholders involved in the acquisition, and integrated across the phases and functions of the system life cycle. In addition, to take full advantage of the investments in these simulations, steps should be taken to ensure that they are reused to support related system programs. This philosophy is often referred to as Simulation Based Acquisition (SBA).

The Acquisition Working Group observed that it will require concerted changes in policy, organizations and relationships, people, resources, and tools if their vision is to become a reality. Within those areas they made the following recommendations.

• Policy. Incentives must be established to motivate stakeholders in the acquisition process to share M&S and data. This might entail providing additional resources to those program managers that manifest this behavior. In addition, there is a need to redefine the roles and responsibilities between government and industry in the acquisition process. It is anticipated that it may require that more of the development responsibility is shifted to industry. Finally, in order to maximize the potential of SBA, changes should be made to enhance the utilization of international products and services.
• Organizations and Relationships. If SBA is to become a reality, it will be necessary to establish partnerships that permit the sharing of data and models. Trust must be a cornerstone of those relationships. Second, the current acquisition process is beset with communities that do not communicate or work effectively with one another. This includes, *inter alia*, users, developers, testers, trainers, and maintainers. It is hoped that if M&S and data can be shared flexibly across those community lines, it will serve to break down those ”stovepipes”. Finally, there is a need to establish dedicated, enduring pilot and flagship programs. Only by pursuing them will the acquisition community know and share enough about the paradigm to make it a routine way of doing business.
• People. People are at the heart of the SBA paradigm. Thus it is critical to educate and train them on the vision and subsequently hold them accountable for achieving the vision.
• Resources. There is an old cliché that if you want to save money, you must first invest money. In the case of SBA, there is a need to make up-front investments in the M&S infrastructure to provide the tools that the community requires.
• Tools. There are four key recommendations in the area of tools to support SBA. First, there must be far greater reliance on M&S in the acquisition process. This use must begin very early in a program and continue throughout its lifetime. Second, there is a need to share this M&S and associated data. This sharing must extend across functional lines (e.g., the developer should share with the trainer) as well as across program lines. Third, there is a need for assured environments within which these M&S can be employed. These environments must be interoperable to facilitate the rapid federation of M&S and secure to allow their use with sensitive and classified information. Finally, since these distributed environments will require the passage of voluminous amounts of data, it would be highly desirable if adequate bandwidth could be made available on demand.

B.2.3 Education & Training. The Education & Training Working Group envisioned a future in which individuals will be educated on “how to learn.” Subsequently, those individuals will receive training (i.e., “how to do”) that is just-in-time, just enough, tailored to needs, and delivered when and where needed. Consistent with that vision, education and training will be integrated, capitalize on research and leverage non-DoD technology advances. In addition,

analysis, acquisition and education and training will provide mutual support and exploit common resources.

The Education and Training Working Group formulated recommendations in six areas: training methods, needs assessment, "come to the people," individual responsibility, life-long process and cross-functional sharing.

• Training Methods. Develop new methods of training in applying the new technologies. DoD must adopt methods that will help change the **way** people learn in addition to **what** they learn. New learning methods that stress the ability to assimilate information will likely be required, instead of traditional methods that focused on memorization or repetition.

• Needs Assessment. Conduct a periodic "Needs Assessment." This assessment will: (1) identify shortfalls in the training and education domains; (2) prioritize these needs and fund efforts to correct them via an implementation plan; and, (3) develop a feedback process that will periodically revise this plan .

• "Come to the People." Make the education and training process significantly more efficient to deal with the consequences of the smaller forces (downsizing), the increased OPTEMPO/PERSTEMPO, and the increasingly complex world. This training/education process must come to the people, and not the people to it. It may be prudent to oversee the application advanced distributed learning (ADL) through the formation of a program office that can coordinate the implementation across all of DoD.

• Individual Responsibility. Individuals must take more of the responsibility for training and educating themselves. In support, DoD must adopt a policy that will provide incentives for individuals to improve themselves through education and training. Likewise, institutions must share in this process so that available resources are not squandered.

• Life-long Process. Implement a life-long education and training process because the world is rapidly changing, the rapid evolution of technology often makes knowledge obsolete within only a few years, and each person needs to be proficient in more skills (fewer people engaged in more complex work). In support of this process, personnel systems must accommodate the need for continuous training throughout the career cycle. To facilitate this process, broad-based training must be integrated with specific, tailored training throughout a soldier's career. Links to non-military institutions of higher learning (e.g., universities, community colleges) will be necessary to expand the knowledge base for such information.

• Establish a Multi-faceted Research Program. A research program is needed in four key areas. First there is a need to capture and extend theory on "how we learn" and "how to teach". Second, it is important to develop human performance metrics to support E&T evaluation. Third, there is a need to capture, store, and make accessible information on individual and organizational performance and E&T system performance. Finally, is vital to create a comprehensive program on Human Behavior Representation.

C. Overarching Findings and Recommendations.

This section briefly summarizes the overarching findings and recommendations that the Workshop developed.

Each of the plenary speakers at the second workshop identified M&S as a key enabler to promote *revolutions* in analysis, acquisition and education and training. This hypothesis was validated by the working groups.

Several of the plenary speakers observed that many of the obstacles to these revolutions are *cultural* in nature. Among the more important cultural obstacles identified were institutional barriers (e.g., the need to go from "stovepiped" organizations to more collaborative organizations that would promote the more efficient sharing of tools, data and expertise); modeling and simulation barriers (e.g., transitioning from the inflexibility of current M&S to more flexible

M&S to explore easily new operational concepts, doctrines, procedures, and the human dimension); and process barriers (e.g., transition from the use of a few, “blessed” scenarios to a full range of scenarios that span the mission space). Again, these observations were extended and validated by the working groups.

From a technology perspective, the working groups concluded that the most significant shortfalls were projected to occur in modeling methodology (i.e., adequate representation of key cognitive factors, performance modulators and computer generated forces); development methodology (i.e., system architecture/engineering; system composability, scalability; and standards for design, interoperability and reuse); and data/information understanding (i.e., tools for dealing with data acquisition, transformation, and access; tools to support collaboration). In almost all cases, these projected technology shortfalls cut across individual functional areas. It is notable that each functional working group also opined that commercial developments in communications and computing would probably *not* constrain M&S applications, with the exception of security needs (see Figure 2).

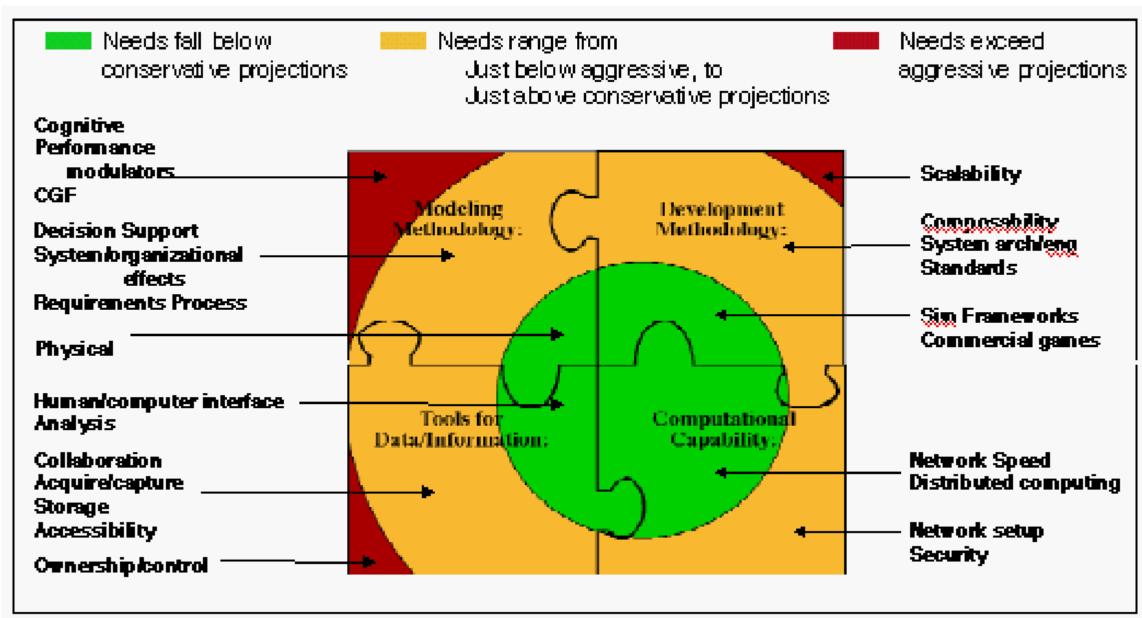

Figure 2: Aggregate Comparison of User Needs and Technology Projections

To facilitate the development of a better balanced M&S Science and Technology (S&T) investment strategy, it is necessary to develop a clear, comprehensive audit trail for current M&S S&T programs and plans.

To promote needed community sharing of tools, data and expertise, organizational focal points are required for SBA and ADL. These organizations should champion these processes, promote pilot programs, monitor commercial developments, begin to establish the community infrastructure needed to “boot strap” the processes and assure the full scope of cross-cutting activities are undertaken (e.g., ensure that education and training needs are treated adequately in SBA).

An expanded family of flexible, readily tailorable M&S is needed to address many user needs. Although on-going monolithic model developments (e.g., Joint Warfare System (JWARS), Joint Simulation System (JSIMS)) will probably prove to be central elements of this family, they will almost certainly not be sufficient to satisfy the needs of all users. To complement them, “boutique” models are needed that address all aspects of the expanding mission space (e.g.,

asymmetric conflict; new operational concepts). These include system dynamics models (to provide the ability to quickly scan and pre-filter scenario space) through virtual M&S (to capture the effects of distributed teams of people under stress). In particular, the demands of advanced warfighting experiments mandate new classes of M&S, which are sufficiently flexible to explore easily new operational concepts, and companion education and training experimentation plans to address the subjects' needs for associated training.

To redress identified M&S technology shortfalls that affect all users of M&S, undertake organized research programs in "soft factors" (e.g., cognitive factors, performance modulators, computer generated forces), data (e.g., tools to capture, transform, and access data) and selected subjects in fundamental / applied research (e.g., agent-based modeling, search and model building; variable structure simulation; multi-resolution modeling; role of interactiveness in discovery and analysis). Mechanisms must also be established to ensure that the results of these research programs are injected into the practice of M&S.

D. … And Beyond

During the last three years, since the conclusion of the SIMTECH 2007 workshops, there have been some notable advances in M&S. The following section briefly summarizes some promising new initiatives as well as major residual issues.

In the area of analysis, there have been several initiatives that have addressed key issues that were identified in SIMTECH 2007. First, SIMTECH 2007 stressed the importance of treating command and control as a first order factor in analyses of defense issues. Consistent with that emphasis, NATO's Studies, Analysis, and Simulation Panel (SAS-03) issued a Code of Best Practice (CoBP) for C2 Assessment (Reference 1). Efforts are underway in SAS-026 to extend the preliminary code beyond assessment of conventional war to include assessments of operations other than war. In addition, SIMTECH 2007 observed that promising developments in the "New Sciences" should be monitored carefully. One promising activity in that area is the USMC's Project Albert (Reference 2). It is in the process of developing new agent-based models, exploring options for orchestrating multiple assessment tools, developing new visualization tools, and developing techniques to perform data farming.

In the area of acquisition, a number of Service initiatives are underway which are attempting to implement the SBA paradigm. The Army is developing a facility at Ft Belvoir, VA, to support the acquisition of key elements of its emerging Objective Force. This Objective Force Battlespace facility, which was formerly known as the Joint Virtual Battlespace (JVB), is using the High Level Architecture (HLA) to federate a number of community M&S assets. Similarly, the USAF at the Electronic Systems Command (ESC), Hanscom AFB, MA, is creating an acquisition environment, the Joint Synthetic Battlespace, to support the acquisition of new C2 systems.

In the area of Education & Training, one of the more interesting developments has been at the Institute for Creative Technologies which the US Army recently established at the University of Southern California, Marina del Rey, CA. The Institute is attempting to take advantage of the techniques developed by the cinema and electronic game industries to develop training tools that are compelling and effective. Early efforts have focused on integrating enhancements in natural language recognition, visualization, and artificial intelligence to generate a prototype system for training small teams in support of operations other than war.

In addition, the DoD is pursuing an Advanced Distributed Learning initiative that is consistent with the SIMTECH 2007 recommendation that training should "come to the people". It is seeking to take advantage of new advances in information systems to enable users to have access to training any where at any time.

Although these recent advances are heartening, there are still major issues remaining that the community must confront. The following represent a few of these issues. In support of analysis, it is widely recognized that there is a need for new tools that enable the analyst to flexibly explore alternative combinations of doctrine, operational concepts, training, leadership and materiel. This is of particular importance in the area of joint experimentation where efforts are underway to assess proposed concepts to transform the US military. In addition, there is a need for tools to support the assessment of critical new missions such as homeland security and counter-terrorism operations. In support of acquisition, it is understood that new M&S tools and environments are necessary but not sufficient to realize the SBA paradigm. If this initiative is to be successful, it will require corresponding changes in culture and people and the philosophy behind the allocation of resources to support acquisition. Finally, the E&T community has residual challenges to confront as it seeks to achieve an initial operational capability with JSIMS. The program has made substantial progress since it embraced the HLA, but there are still substantial challenges associated with completing and federating the key component simulations.

E. References

1. RTO-TR-9 AC/323(SAS)TP/4.*Code of Best Practice (COBP) on the Assessment of C2*. Neuilly-Sur-Seine Cedex, France, March 1999.
2. Project Albert, http://www.projectalbert.org

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The Method of Construction and Learning of Local Combat Generator

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ABSTRACT

A new approach to military conflict modeling and analysis is presented. The combat models for local clashes are implemented in a simulation language in the application. The construction process of local combat generator is presented. Main components of the tool are described and the process of input and output identification is considered. The mathematical model of the combat generator there is a multidimensional table. The procedure of fulfilling the table there is the learning process based on the set of simulation experiments. Another procedure there is utilization of knowledge consisted in the table. Possible directions of the development and utilization of the local combat generator are discussed.

INTRODUCTION

An approach to military conflict modeling is presented. As a conflict situation a battle on battalion level is considered. The combat process is very complicated. Many factors can course the complexity of the process. Among these factors the most important that significantly effect the combat process course are:

- number and type of armament which participate in a battle for both sides;
- terrain conditions of a battlefield. It means:
  - form (shape) of terrain,
  - type and occurrence of vegetation on the terrain,
  - kind of ground;
- atmospheric and weather conditions i the battlefield:
  - type and occurrence of atmospheric precipitations,
  - time and season,
  - temperature, pressure and humidity;
- type of combat units activity (an attack, a defense or a movement);
- state of soldiers training and morale;
- specificity of warfare for different types of unit;
- state of command, control and communication system.

The local combat is defined as a clash of two formations which consists in direct fire of two sides under optical visibility. The main purpose of local combat model construction is to obtain an answer for the question:

> "How is resource decrease process running and how is fighting formations' location changing when we know the state of the process before the battle?"

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

MODEL OF LOCAL COMBAT GENERATOR

We propose to build the specific tool which allows us to generate combat result very quickly. The generated combat results, for the initial conditions determined (as a scenario), should provide an information about:

- the combat duration,
- the evaluation of formations' state:
  - the number of soldiers, weapons and vehicles that are capable to use,
  - the location and the velocity of a unit.

The tool there is a procedure of service of multidimensional matrix

$$GW = \lfloor gw_{i,j,\dots,k} \rfloor_{I \times J \times .. \times K} .$$

The element of the matrix $gw_{i,j,\dots,k}$ there is a vector of probability distributions (empirical) of output magnitudes which are obviously random variables.

The input magnitudes are stochastic processes which have many states. The particular element of a matrix can be identified by an index (i, j, …, k) which indicates the number of a state for each individual input magnitude. The symbols I, J, …, K represent numbers of permissible states of an appropriate input magnitude. The input magnitudes' state describes the scenario of the combat it means the initial conditions of the warfare process. Generally, the generation method of the local combat results consists in two main steps:

1. the identification of a scenario to which the particular military conflict situation fits very closely. This identification consists in finding the indices which indicate the appropriate states of input parameters of a combat process.
2. after we found the scenario indices we then look at the matrix to find a right cell with a probability distributions vector. According to them we generate values of output magnitudes.

To illustrate the conception and the construction way of the generator let us assume that it is a black box with a specific service procedure (figure 1).

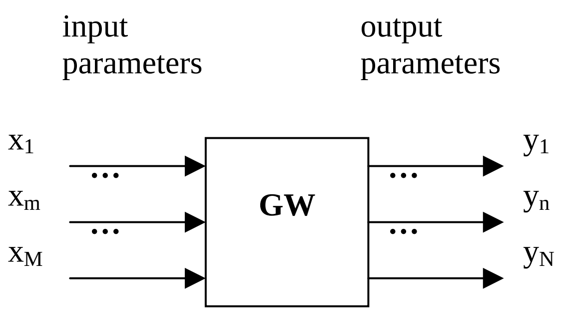

Fig. 1. Idea of generating of battle results.

Let $X = (X_1, X_2, \dots, X_m, \dots, X_M)$ be an input variables vector which defines a warfare scenario (an initial battlefield condition) and $X \in \mathbf{X} = \mathbf{X_1} \times \mathbf{X_2} \times \dots \times \mathbf{X_m} \times \dots \times \mathbf{X_M}$ (M – number of the scenario elements).

X_m - input variable which describes the specific scenario element for instance:

- kind of a unit (mechanized battalion),
- unit status:
  - manpower,
  - equipment status,
- state of logistics supplies (ammunition, fuel),
- kind of a activity taken by a unit (attack, defense, movement)
- battlefield conditions:
  - terrain type,
  - atmospheric conditions.

$X_m \in \mathbf{X_m} = \{x_m^{(1)}, x_m^{(2)}, \dots, x_m^{(i)}, \dots, x_m^{(I)}\}$ and $x_m^{(i)}$ - the i-th state of the variable X_m, $i \in \{1,2,\dots,I\}$ (I – number of values of $\mathbf{X_m}$ set).

$\mathbf{X_m}$ - the set of specified permissible values of the m-th initial battlefield condition. The set can be discrete and limited because of the generator construction requirements. We should identify the multidimensional matrix GW cells. As mentioned we do identification by the indices $(i, j, ..., k) \in \mathbf{I} \times \mathbf{J} \times ... \times \mathbf{K}$ which indicate the appropriate input variables' vector state. The number of the specified states $\mathbf{I}, \mathbf{J}, ..., \mathbf{K}$ is a construction decision and depends on required accuracy of the local combat generator model. It also causes influence a length of a "learning" process of the generator. The learning process consists in conducting of experiments with the simulation model and an analysis of these outcomes to determine the unknown distributions of the output battle results.

Let $Y = (Y_1, Y_2, ..., Y_n, ..., Y_N)$ be the output variables vector of the generator GW ($Y \in \mathbf{Y_1} \times ... \times \mathbf{Y_n} \times ... \times \mathbf{Y_N}$). It represents in general sense results of a battle of two conflict sides A and B where:

a) $Y_1 = (Y_{11}, Y_{12}, ..., Y_{1s}, ..., Y_{1S})$ - the discrete random variable vector which describes a number of weapons of a particular type of A side after a clash is over.
   $Y_1 \in \mathbf{Y}_{11} \times \mathbf{Y}_{12} \times ... \times \mathbf{Y}_{1s} \times ... \times \mathbf{Y}_{1S}$ where $\mathbf{Y_{1s}} = \{0,1,2,3,...\}$ (S – number of weapon types for side A).
b) Y_2 - for side B respectively.
c) Y_3 - the continuous random variable which represents the battle duration.
   $Y_3 \in \mathbf{Y}_3 = \boldsymbol{R}^+ \cup \{0\}$.
d) Y_4 - the binary random variable which indicates who has won (lost) the battle.
   $Y_4 \in \mathbf{Y}_4 = \{0,1\}$ where
   0 – indicates that the loser is side A however
   1 – indicates that side A is the winner.
e) etc.

The size of the output variable can be of course extended. The described four elements of vector Y are to illustrate the idea of the construction and learning of the local combat results generator.

Now we can define the cell of the generator matrix GW:

$$gw_{i,j,...,k} = \langle F_1(y_1 \mid (i, j, ..., k)), ..., F_N(y_N \mid (i, j, ..., k)) \rangle$$

where $F_n(y_n \mid (i, j, ..., k))$ - conditional probability distribution of random variable Y_n for (i, j, …, k) scenario. Considering that the scenario effects the form of the probability distributions F_n of Y_n ($n \in \{1,2,...,N\}$) we will conduct series of simulation experiments for each scenario separately. The accuracy of the distributions' approximations strongly depends on number of experiments. Assume that we have conducted L simulation experiments for a specific scenario. The received outcomes of Y_n is as follow $Y_n^* = \{y_{n1}^*, y_{n2}^*, ..., y_{nL}^*\}$. Now we transform the set Y_n^* to a increasing sequence of couples (y_{nk}, n_k) where

$$y_{nk} \in Y_n^* (\forall k \in \{1,2,...,K\}) \ ,$$

$$y_{nk} \prec y_{nk+1} \ ,$$

$$n_k = card(y_{nl}^* : y_{nl}^* = y_{nk}) \ , \ \sum_{k=1}^{K} n_k = L \ .$$

Then we calculate the values of probability $P\{Y_n = y_{nk}\} = p_k^{(n)}$ in the following way:

$$p_k^{(n)} = {n_k}/{L} \ , \ (\forall k \in \{1,2,...,K\}) \ .$$

When we compute probability vector $p^{(n)} = (p_1^{(n)}, p_2^{(n)}, ..., p_K^{(n)})$ then we can define probability distribution:

$$F_n(y_n) = \begin{cases} 0, & \text{for } y_n \le y_{n1} \\ p_1^{(n)}, & \text{for } y_{n1} < y_n \le y_{n2} \\ \quad ... & \\ \sum_{i=1}^{k} p_i^{(n)}, & \text{for } y_{nk} < y_n \le y_{nk+1} \\ \quad ... & \\ 1, & \text{for } y_n > y_{nK} \end{cases}.$$

The second way of a battle results' description is to determine the functional dependences between the random variable *Y* and the scenario *X* (those elements of a scenario which can be measured). Such dependences can describe regression functions of *Y*.

LEARNING METHOD

To fulfill the matrix of the generator we can use experimental data. These data can be simulated or real (exercises output or historical data) as well. To do this we have used the interactive simulation system MSCombat [1],[2],[8] (figure 2). It is a simulation environment which enables us to conduct military land simulations. There are implemented some local combat models. The application allows us to define battle scenarios using a GUI with the complex menu, dialogs and icons system (figure 3). After scenario definition we may run series of simulation experiments. There is a possibility to gather many interesting output characteristics of battle process during simulation experiments. To utilize statistical methods to determine the probability distributions of output magnitudes we have to run many simulation experiments under the same initial conditions (scenario).

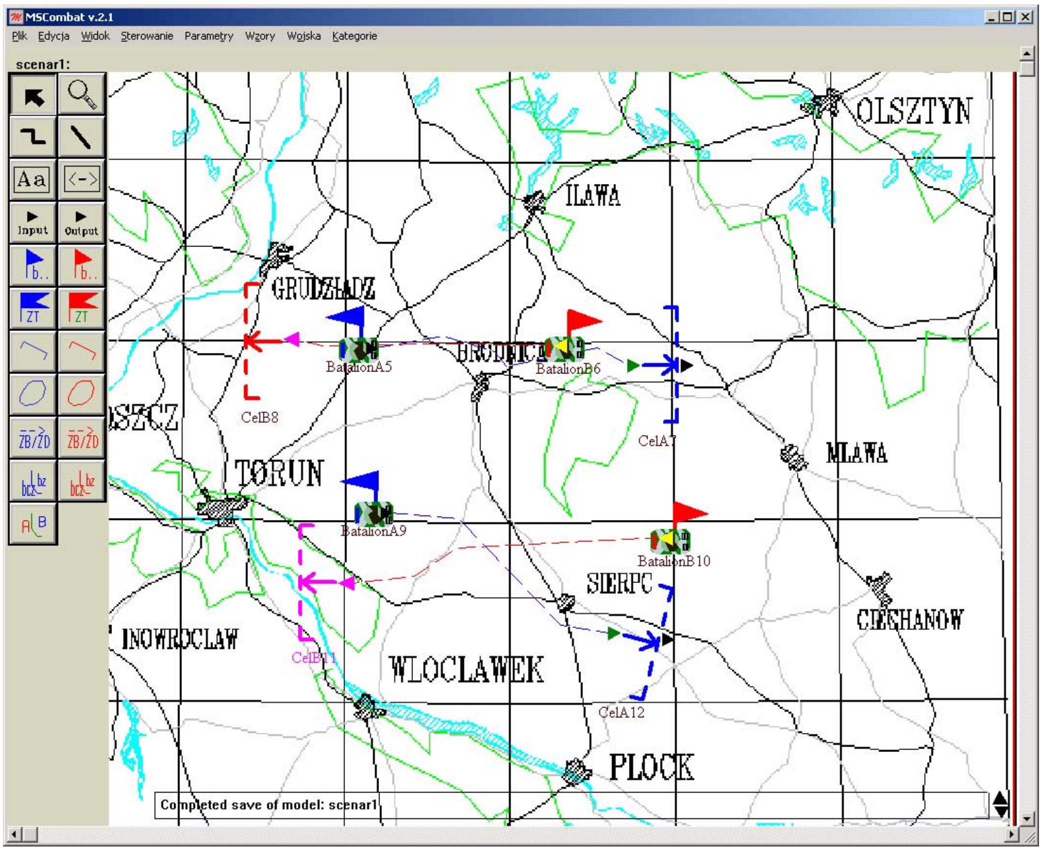

Fig. 2. MSCombat application.

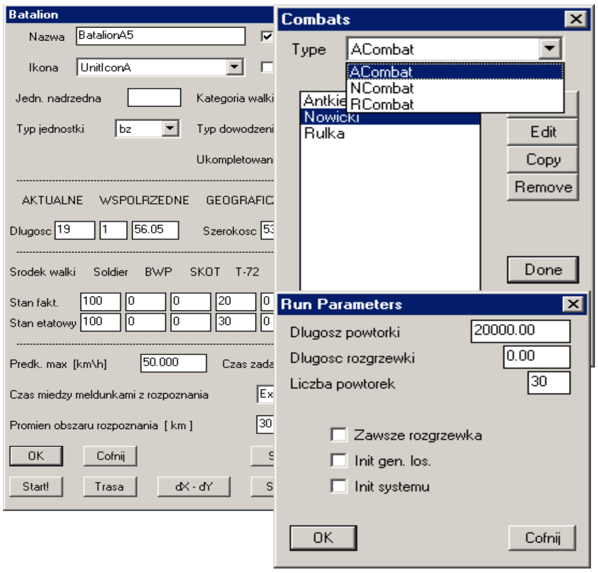

Fig. 3. Dialog windows:
- **a. a unit state definition**
- **b. a combat model definition**
- **c. simulation parameters definition.**

LOCAL COMBAT MODEL

Assumptions

To determine the generator matrix GW we can use our own combat models. The models have been recently developed within the confines of researches conducted in Military University of Technology, Cybernetics Faculty [3],[5],[6]. One of them is the simulation combat model with dynamic fire control. It is an attempt of a description of two sides clashes at the battalion level. We assume that the combat is local. It means that combatants lead a direct fire into opponents under optical visibility and under similar terrain and atmospheric conditions. It is obvious that the locality assumption is not always true in the real world. But if we consider that the warfare applies to small formations which naturally operate in a local area, this simplification seems to be acceptable. Additional assumptions are as follows:

1. two sides of a battle A and B are equipped with heterogeneous armament weapons;
2. each of the weapon is characterized by different properties:
   a. p_{rs} - a probability of one shot hit by combat mean of type “r” to target s-type. The value of this parameter is not constant and depends on e.g.: a distance between opposing weapon systems, terrain and atmospheric conditions of a battlefield;
   b. λ_r - the fire intensity of r-th type combat mean. The parameter either is not constant and depends on e.g.: a level of logistics supplies (ammunition and fuel), a kind of a unit activity (attack, defense, movement);
   c. a_{rs} - the coefficient which characterizes a resistance of a specific r-type weapon from s-type weapon direct fire. It has a measure of a conditional probability of one shot killing when target has hit;
   d. D_r - the range of a effective fire of a r-type weapon. This parameter limits the specific weapon availability during a battle;
   where
   $r \in \{1,2,\ldots,R\}$, $s \in \{1,2,\ldots,S\}$ and R, S represent numbers of weapon types for each conflict side (adequately A and B).
   e. during the course of a battle there is no possibility of reinforcement (soldiers, ammunition, fuel);
   f. the command, control and communication system works properly for both conflict sides.

Generally, the presented combat model describes a warfare like a multistage process of alternate optimal decisions calculation and their simulated realization. The decisions (for both A and B side respectively) apply

to combat means allocation and there are determined in each stage of the battle process. The simulation of the decisions' effects for a chosen stage we can describe as a multidimensional stochastic semi-Markov process

$$\xi(t) = (\xi^A(t), \xi^B(t))$$

of DC class (discrete in states and continuous in time). The effects of destroying interactions concern to the current armament.

$$\xi^{A(B)}(t) = \left[\xi_{rs}^{A(B)}(t)\right]_{R\times S}, \text{ where}$$

$\xi_{rs}^{A(B)}(t)$ – represents a number of a r(s)–type weapon of side A(B) which has been allocated to fire to s(r)–type weapon of side B(A).

Object model implementation

For the described combat model we have defined and implemented following classes of objects: CombatCategoryLibMgrObj, CombatCategoryListMgrObj, CombatCategoryQObj, CombatCategoryObj, CombatQObj, CombatObj, UnitObj, UnitQObj. The simplified implementation structure of the combat model objects relations illustrates figure 4 where the numbers on arcs signify the numbers of appearances of objects in relations.

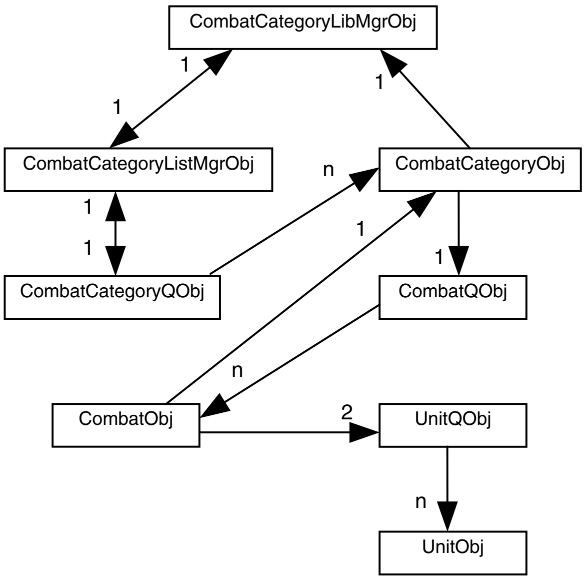

Fig. 4. The relation structure of simulation combat model objects.

One of the main implementation combat model object class is CombatObj. It is responsible for the particular battle process course, it means the process of losses of resources and a movement of formations' elements. The definition of the CombatObj class is as follows:

```
CombatObj = PROTO;
      otype  : CombatCategoryObj;
      qunitA : UnitQObj;
      qunitB : UnitQObj;
      bEnd : BOOLEAN;
      ASK METHOD SetMgr(IN mgr: CombatCategoryObj);
      ASK  METHOD SetSides(IN a:UnitObj; IN b:UnitObj);
      ASK  METHOD UpdateState(IN side:UnitQObj);
      ASK  METHOD InitBattle;
      TELL METHOD Battle;
      ASK  METHOD TerminateBattle;
END PROTO;
```

A temporary CombatObj instance is created by an appropriate combat category CombatCategoryObj for only the warfare duration. Two conflict sides which participate in a battle are represented by UnitQObj. The CombatCategoryObj is a class that manages the CombatObj's of its own type. It creates CombatObj instances in the specific moments and then removes objects when the battle is over. The CombatCategoryObj also consists some additional parameters and structures which are typical and common for all created CombatObj's instances. The CombatCategoryObj is also used to gather some interesting characteristics deal with the combat process during simulation.

```
CombatCategoryObj = PROTO(LibEleObj[LibListMgrObj]:
                                   CombatCategoryListMgrObj]);
     qcombat : CombatQObj;
     bActive : BOOLEAN;
     uniSamp : SampleObj;
     ASK METHOD CreateCombatQ(): CombatQObj;
     ASK METHOD CreateCombat(): CombatObj;
     ASK METHOD CreateAndInitCombat(IN kto:UnitObj;
                                   IN zkim: UnitObj);
     ASK METHOD TerminateCombat(IN comb: CombatObj);
      ASK METHOD AttachToCombat(IN kto: UnitObj;
                                   IN zkim: UnitObj);
     ASK METHOD SetActive(IN b : BOOLEAN);
     ASK METHOD LibMgr() : LibMgrObj;
END PROTO;
```

CombatQObj, CombatCategoryQObj, UnitQObj – those additional classes are designed for a maintenance and management of following objects' queues: CombatObj, CombatCategoryObj, UnitObj. The other object classes: CombatCategoryLibMgrObj and CombatCategoryListMgrObj are essential to manage the combat category library and allow us to define and create new combat categories in a scenario.
The presented object model of a local military conflict is an open platform to develop new combat models in the future.

SCENARIO EXAMPLE

Let consider the warfare of two formations A and B. The A unit is a tank battalion which equipped with 25 tanks (of 30) leads an attack against the unit B. However the B is a mechanized battalion which has got different weapons: 300 rifles (of 300), 20 APCs (of 30) and 10 guided anti-tank bullet launchers (of 10). The simulation experiments have been conducted for specified conditions. The results are gathered in the table 1. The analysis were made using statistical package SPSS v. 10.

Table 1.

Number	tanks_a	rifles_a	APCs_a	gatbls_a	duration	Number	tanks_a	rifles_a	APCs_a	gatbls_a	duration
1	12	231	5	6	44,07	16	12	231	5	6	44,07
2	11	236	6	4	34,30	17	12	231	5	6	44,07
3	12	231	5	6	44,07	18	22	242	5	5	16,22
4	14	237	5	5	28,58	19	14	237	5	5	28,58
5	12	231	5	6	44,07	20	12	231	5	6	44,07
6	14	237	5	5	28,58	21	11	236	6	4	34,30
7	12	231	5	6	44,07	22	14	237	5	5	28,58
8	14	237	5	5	28,58	23	22	242	5	5	16,22
9	22	242	5	5	16,22	24	11	236	6	4	34,30
10	14	237	5	5	28,58	25	14	237	5	5	28,58
11	20	246	5	7	12,84	26	14	237	5	5	28,58
12	22	242	5	5	16,22	27	14	237	5	5	28,58
13	14	237	5	5	28,58	28	12	231	5	6	44,07
14	12	231	5	6	44,07	29	22	242	5	5	16,22
15	14	237	5	5	28,58	30	14	237	5	5	28,58

The probability distributions of: the battle duration and number of weapons after the battle for this scenario are presented in figure 5.

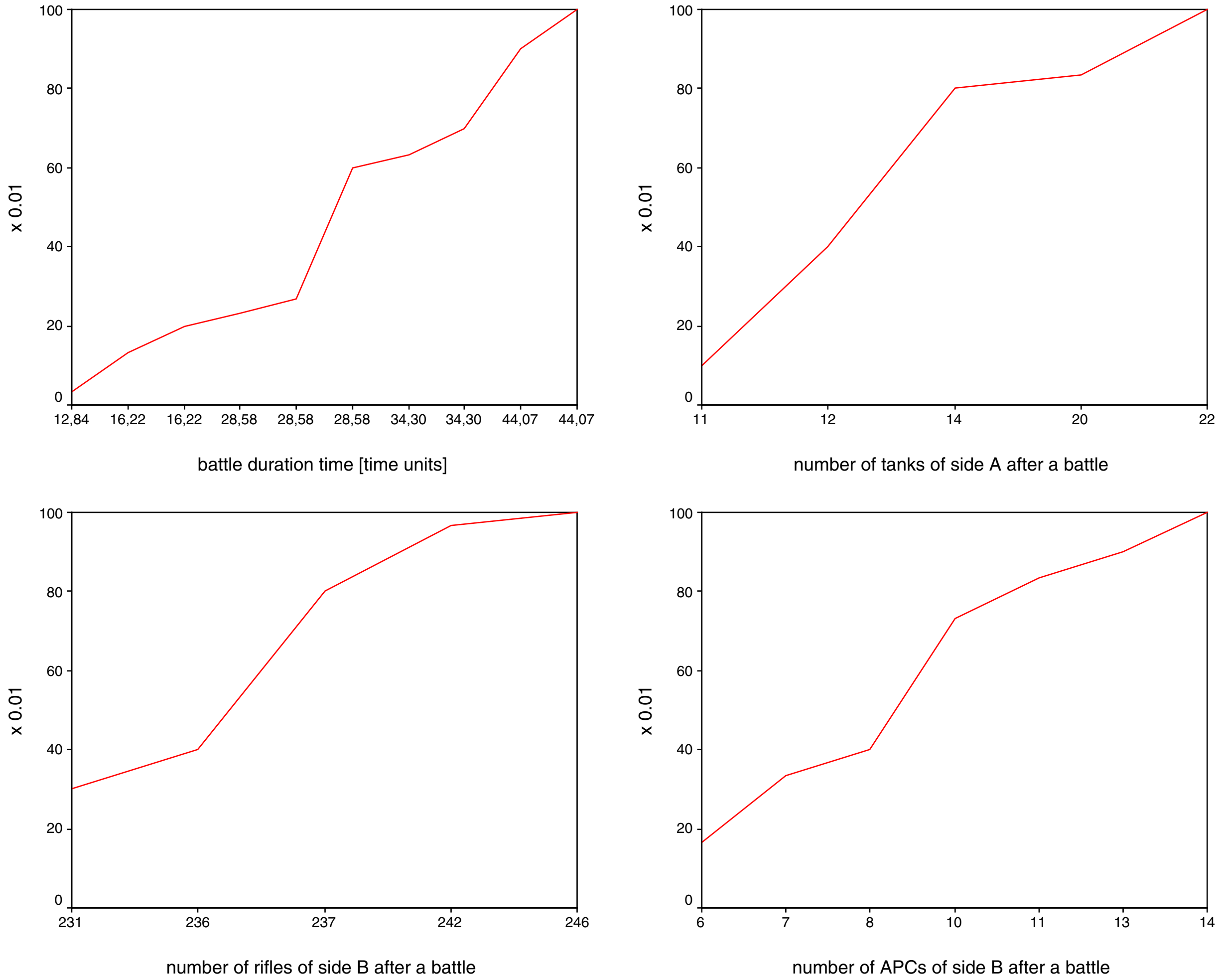

Fig. 5. Probability distributions of the battle results.

POSSIBLE APLICATIONS AND DEVELOPMENT DIRECTIONS

This generator can be used as:

- a tool for quick receiving of local combat result;
- an element of knowledge base for decision support system and simulation system;
- a method of comparison of different combat models;
- a method of evaluation of payoff in a theory game model (in armed conflict).

Very interesting usage of the generator seems to be the comparison method in a verification, validation and accreditation (VVA) process. The presented method of local combat results generating is based on the specific combat model representation as a multidimensional matrix of probability distributions and / or regression functions. Thus this way of a model representation allows us to compare different models objectively on the same platform. It means that the models comparison is done statistically by using an appropriate probability distribution of output process variables for the same initial parameters values (conditions).

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Multiagent Work Practice Simulation: Progress and Challenges

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Summary

Modeling and simulating complex human-system interactions requires going beyond formal procedures and information flows to analyze how people interact with each other. Such *work practices* include conversations, modes of communication, informal assistance, impromptu meetings, workarounds, and so on. To make these social processes visible, we have developed a multiagent simulation tool, called Brahms, for modeling the *activities* of people belonging to multiple groups, situated in a physical environment (geographic regions, buildings, transport vehicles, etc.) consisting of tools, documents, and computer systems. We are finding many useful applications of Brahms for system requirements analysis, instruction, implementing software agents, and as a workbench for relating cognitive and social theories of human behavior. Many challenges remain for representing work practices, including modeling: memory over multiple days, scheduled activities combining physical objects, groups, and locations on a timeline (such as a Space Shuttle mission), habitat vehicles with trajectories (such as the Shuttle), agent movement in 3d space (e.g., inside the International Space Station), agent posture and line of sight, coupled movements (such as carrying objects), and learning (mimicry, forming habits, detecting repetition, etc.).

Background: Brahms and Work Practice Modeling

A Brahms model of work practice (Clancey, et al., 1998) reveals *circumstantial, interactional influences* on how work actually gets done, especially how people informally involve each other in their work, thus changing the quality of the result. In particular, a model of practice reveals how collaboration is accomplished in communications, including meetings, email, workflow systems, and written documents (Wenger, 1998). Choices of what and how to communicate are dependent upon *social beliefs and behaviors*—what people know about each other's activities, intentions, and capabilities and their understanding of the norms of the group. As a result, building a Brahms model leads human-computer system designers to question *how tasks and information actually flow* between people and machines, what work is required to synchronize individual contributions, and how tools hinder or help this process (Greenbaum & Kyng, 1991; Bagnara, 1995). In particular, workflow diagrams generated by Brahms are *the emergent product of local interactions between agents and representational artifacts*, not pre-ordained, end-to-end paths built in by a modeler.

To illuminate how formal flow descriptions relate to the social systems of work, Brahms incorporates multiple views—relating people, information, systems, and geography—in one tool. Such views help work system designers, managers, and trainers better understand the interactive, circumstantial

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importance of proximity of people and tools to each other, timing of individual interactions, and how attention is conceptually scoped by work settings and roles. Accordingly, we begin to see how work flow is an abstraction; actual work is accomplished and practices learned through often chance interactions, which are omitted from most process models and written procedures.

Brahms was originally developed as a research tool at a telecommunications company (NYNEX) and the Institute for Research on Learning. More recently, Brahms is being applied at NASA for crew scheduling, human-robot system design, and operations assistants in extreme environments. An example is presented in subsequent sections to illustrate the components and operation of Brahms simulations. Many challenges remain for representing work practices, which we discuss at some length in the last part of this paper.

Basic Components of a Brahms Simulation

A Brahms simulation of work practice has seven components:

Agent Model: The group-agent membership hierarchy of the people in the work system. Groups may be formal roles and functions or based on location, interpersonal relations, interests, etc.

Object Model: The class-hierarchy of all the domain objects and artifacts, e.g., tools, desks, documents, vehicles.

Geography Model: The geographical areas in which agents and objects are located, consisting of area-definitions (user-defined types of areas, such as buildings, rooms, and habitats) and areas (instances of area-definitions).

Activity Model: The behavior of agents and objects in terms of the activities they perform over time (Clancey 1997). Agent or object activities are mostly represented at the group-level or class-level respectively, but are also often specific to agents and objects. Activities are inherited and blended through a priority scheme.

Timing Model: Constraints on when the activities in the activity model can be performed, represented as preconditions of situation-action rules (called *workframes*). Activities take time, as determined by the predefined duration of primitive actions. Workframes can be interrupted and resumed, making the actual length of an activity situation dependent.

Knowledge Model: An agent's reasoning, represented as forward-chaining production rules (called *thoughtframes*). Thoughtframes can be represented at group/class levels and inherited. Thoughtframes take no time. Inquiry is modeled as a combination of activities (e.g., detecting information, communicating, and reading/writing documents) and thoughtframes. Perception is modeled as conditions attached to workframes (called *detectables*); thus observation is dependent on what the agent is doing.

Communication Model: Actions by which agents and objects exchange beliefs, including telling someone something or asking a question. A conversation is modeled as an activity with communication actions, either face-to-face or through some device, such as a telephone or email. The choice of device and how it is used are part of the work practice.

Typically a Brahms model is sketched by specifying the geography and groups first. The grainsize of the simulation clock (time per tick) may vary from 5 seconds or less to 5 minutes or more, depending on the information available and modeling purposes. A model might represent a group of people as a single agent, a useful heuristic in redesigning a work system. Common objects and activities such as telephones and “phone conversation” may be easily reused and adapted from other Brahms models. In general, Brahms models represent work with much more detail than business process models, but somewhat less detail (and far more broadly) than cognitive models. Considerable effort is devoted to modeling objects (e.g., fax machines) and computer systems, with which people interact to accomplish their work.

Comparison to Other Process Modeling Methods

Traditional human factors approaches tend to start with specifications or machinery and study the deficiencies in human behavior (i.e., “performance”) with respect to the predefined requirements of the task or systems to be operated. This approach tends to focus on developing tools (such as tests) to predict how people will perform and then developing training to improve human performance.

A complementary approach is possible. One can start instead with a “bottom up” study of people in their work setting and study how they interact to accomplish their goals, including communication, learning, and work arounds. The emphasis is not on human failures, but on success: How do people succeed despite the deficiencies of their tools and given the inherent conflicts and ambiguities in the work situation? The emphasis of this approach, which we call “work systems design” is on improving the tools, procedures, and facilities. Can we invent new ways of using computers, for example, which better fit human preferences and ways of learning, rather than fitting people to given procedures and tools? Rather than just changing the interface, can we reconceive how the work is done? This same perspective, which focuses on *deficiencies of machines* relative to human capabilities, is essential for developing better “intelligent” computer tools.

Brahms is a simulation tool for representing the interactive behaviors of people and objects in a simulated world. The focus is on how people, tools, and the environment influence each other, such that a total system can be understood and improved. Perhaps the best way to describe Brahms is to contrast its architecture, model content, and how models are developed with other modeling tools:

- Architecture
  - Components are modular and reusable (groups, agents, locations, objects, etc.).
  - Brahms models behaviors, not just inferences; work product flows are output from model, not specified.
  - Behaviors are activated via subsumption (parallel activation; not a procedure stack, activities are not functions or tasks, but how people conceptually organize their time, e.g., relaxing in the evening).
  - Attention (perception of the world) is scoped by activity; i.e., what an agent notices depends on what he/she is doing.
- Content
  - Environment is modeled explicitly, including movement of people through offices, rooms, buildings, and geographic locations (e.g., space station modules).
  - Environment, objects, and agent behaviors interact (not just describing work flow or reasoning).
  - Models represent more detailed causal relations than in conventional process models, indicating how connectivity happens (how processes flow, not just drawing lines between boxes or specifying mathematical relations).
  - Primary focus is on whose knowledge is called into play (participation influences work quality) not what idealized knowledge is required to perform a task.
- Development and Use
  - Ethnography (observing as a participant in the work setting) is primary source of data.
  - Video analysis (of everyday work setting) is essential source of data.
  - Participatory design (including people being studied in the design team) provides primary context for developing and using models.

In effect, Brahms derives from the sociotechnical systems approach of the 1950s (e.g., see Corbet, Rasmussen, and Rauner, 1991), realized in object-oriented computer simulations that combine the methods of qualitative modeling ("artificial intelligence"), cognitive modeling ("knowledge-based systems"), and interactive rendered displays ("virtual reality" and "web-based browsers"). Perhaps most

important, Brahms modeling involves a thorough collaboration between social and computer scientists, so interpersonal relations and information processing perspectives are related throughout the study and design process.

Since the initial design of Brahms in the early 1990s, other “multiagent” modeling systems have been developed (see Clancey et al., 1998 for references). No single system is superior for all applications, but we can describe some of the advantages of Brahms relative to other advanced technologies:

- Architecture
  - Agents (and objects) are both deliberative (actions derive from inferences using models of behavior and the environment) and reactive to the environment (actions are immediate and associational).
  - Agent beliefs are independent of facts representing the state of the world.
  - Conceptual objects (e.g., “job orders”) allow tracking and abstracting actions (e.g., for determining total time and cost associated with particular work products such as customer orders).
  - Java interface (“API”) facilitates integrating other simulations.
- Content
  - Represent communication between agents and objects, plus the communication tools used in specific situations (e.g., fax, phone, email, pager).

Example Application: Victoria Proposed Lunar Mission

To introduce the components of Brahms’ language and the nature of the models that can be constructed, we describe a model of a mission operations for Victoria, a proposed long-term semi-autonomous robotic mission to the South Pole region of the Moon. The primary mission objective is to verify the presence of water ice and other volatiles within permanently shadowed regions (Cabrol, et al, in press). During such a traverse the rover will use its neutron detector instrument to detect hydrogen and the Sample Acquisition and Transfer Mechanism (SATM) to drill into the lunar surface and take surface samples to be investigated using an array of science instruments. The essential problem is that the robot needs to have enough power to make it safely out of the dark region before its battery is empty. This makes power consumption a very important constraint in the design of the robot.

MISSION OPERATIONS SYSTEM DESIGN

The work during the Victoria mission will be distributed over a number of human teams and the Victoria rover. By virtue of being people’s arms and eyes on the Moon, the teleoperated rover is more of an *assistant* than a simple tool.

Figure.1 represents the work system elements and their relative location during the Victoria mission. The Science Team consists of co-located sub-teams: the Science Operations Team (SOT), the Instrument Synergy Team (IST), and the Data Analysis and Interpretation Team (DAIT). There are two other supporting teams: The Data and Downlink Team (DDT) and the Vehicle and Spacecraft Operations Team (VSOT). The teams communicate with the Victoria rover on the lunar surface using the Universal Space Network (USN), directly and via a lunar orbiter.

The data from the rover will consist mainly of contextual and multi-spectral image data, but will also include thermal emission, a variety of spectrometer data, and microscopic imaging. This data will be automatically converted in near real-time to accessible formats made available to the teams via data visualization applications.

Based on previous experience, the designers hypothesized that the decision cycle of the science team will be affected by many issues, one of which is data overload. They therefore specifically addressed the following questions in the work system design for Victoria:

1. How will science data be gathered collaboratively with the Earth-based science team, rover teleoperator, and the rover on the lunar surface?
2. How will science data be made available to the science team?
3. What is the affect of a particular work system design on the power consumption of the rover during a science traverse into a permanent dark crater?

To answer these questions, Sierhuis (2001) and others developed a model of the activities of the teams, based on the description of a planned mission traverse. In the next sections we describe the design of this work system through the design of the agent model, the object model, their activity models, and the geographical model.

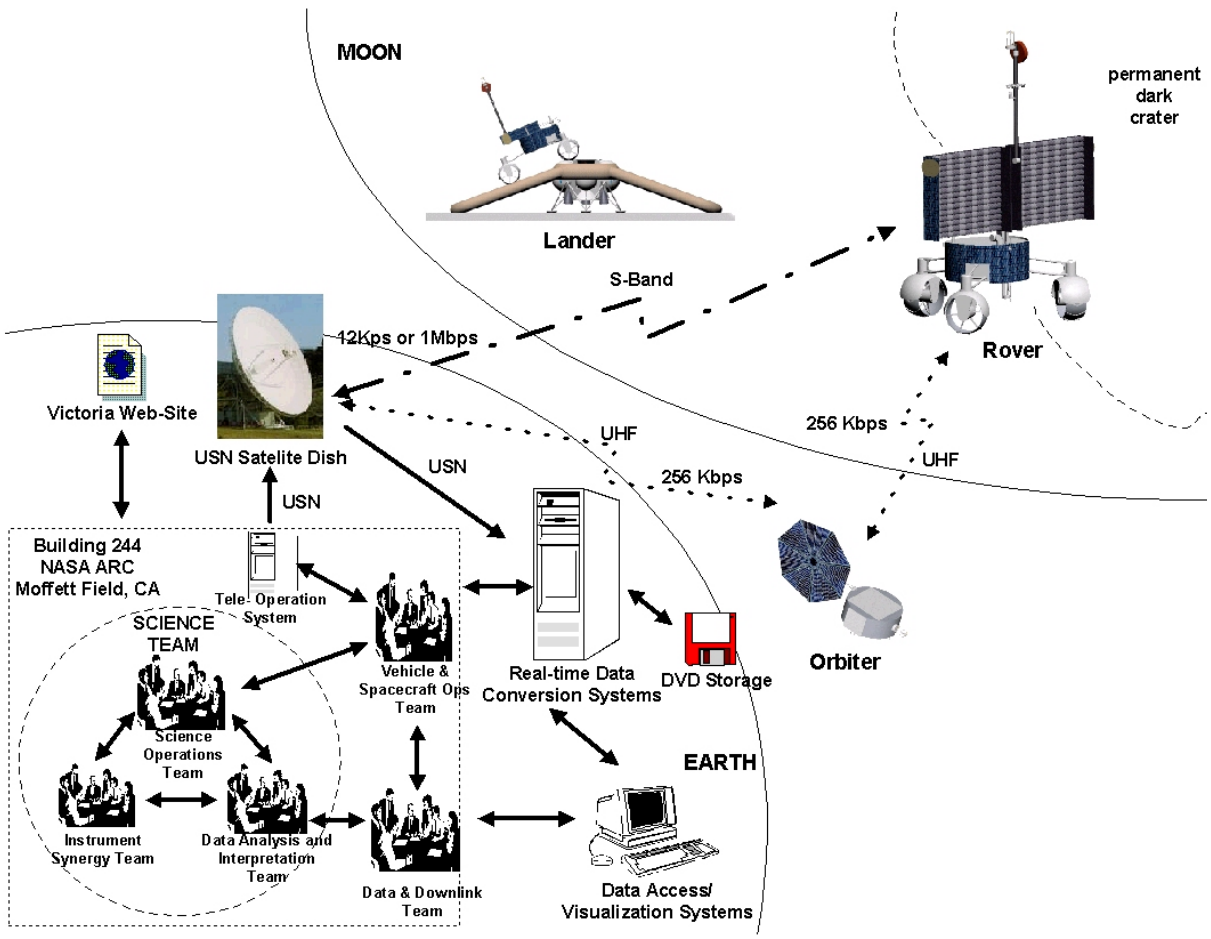

Figure.1. Victoria work system

AGENT MODEL DESIGN

Figure 2 shows the group membership hierarchy on which the design of the work system is based. The agents in the model are the Earth-based human teams and the Victoria rover, as shown in Figure.1. The teams are represented as agents, because it is not yet possible to prescribe the composition and practices of each team in more detail. For example, the “plan a command sequence” activity of the SOT represents the work of the whole team, while the individual activities of each team member remain unspecified. The Victoria Rover is modeled as an agent because it has activities, including primitive actions that change the world, movements, and communications.

Table 1 shows a possible distribution of mission functions over the Victoria teams (Wall, 1991). Details of how different teams collaborate to perform these functions constitute the work practice, as specified in the situation-action rules (Brahms *workframes*) of the different agents. An example workframe for an SOT agent for creating a command sequence for finding water ice is (paraphrased): When I believe that there is a possibility we can find water ice at the current location of the rover, then start the activity of finding water ice. Generically, a workframe is of the form: *When (I believe X*) Do {activity A, conclude a new belief and/or fact}*.*

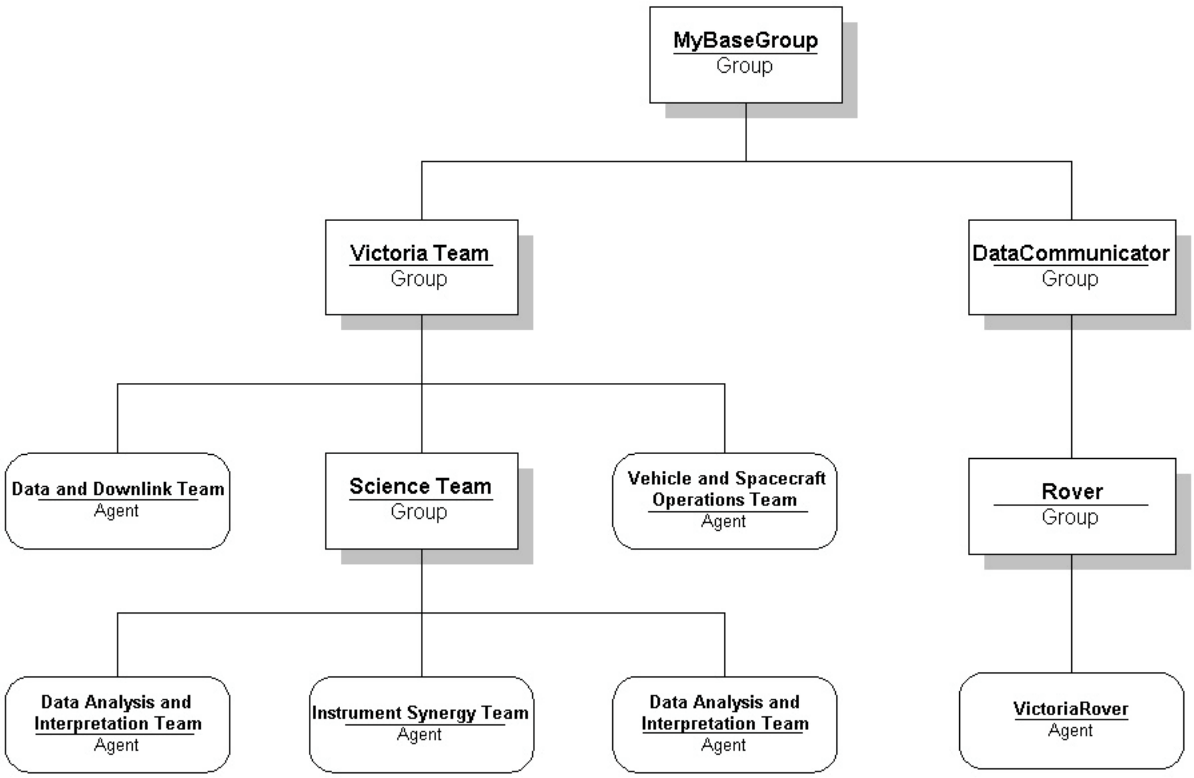

Figure 2. Victoria Agent Model

Object Model Design

The object model consists of the classes and instances of physical artifacts, as well the statically and dynamically created data objects during the simulation. The Victoria object model (Figure 3) includes classes for the science instruments on the rover and other objects contained in the rover, such as the carousel and the battery. Furthermore, the model includes the data communicator class, which includes the objects for S-band and UHF communication. The model also includes the software systems that receive and convert the mission data. A Brahms object represents the data visualization systems that present data to the Victoria team. The Data and CoreSample classes allow dynamically creating objects representing specific data and lunar core samples during the simulation.

GEOGRAPHY MODEL DESIGN

The geography model represents locations on Earth and the Moon (Figure 4). The areas of interest on Earth are Building244, where the Victoria teams and systems are located, and UsnSatelliteLocation, where the UsnDish1 satellite dish is located. Locations for the simulated scenario are represented on the Moon. ShadowEdgeOfCraterSN1 represents the location of the rover at the start of the simulation (the shadow edge in crater SN1). ShadowArea1InCraterSN1 represents the area in the permanent shadowed SN1 crater where the rover will perform a drilling activity. The LandingSite area is represented only for completeness.

Table 1. Functional activity distribution over Victoria teams & Rover

	Science Operations Team	Instrument Synergy Team	Data Analysis and Interpretation Team	Data and Downlink Team	Vehicle and Spacecraft Operations Team	Rover
Uplink process	Maneuver commands Command sequences for experiment operation	Commands for engineering operation of robot/ spacecraft Emergency or anomaly resolution commands	Long-term planning for science opportunities	Telecomm-unication commands	Maneuver commands Command sequences for experiment operation	Command execution
Downlink process		Monitoring of health and status telemetry from robot subsystems	Data quality assessment Experiment data collection	Experiment data collection Data processing and enhancement		Experiment data collection

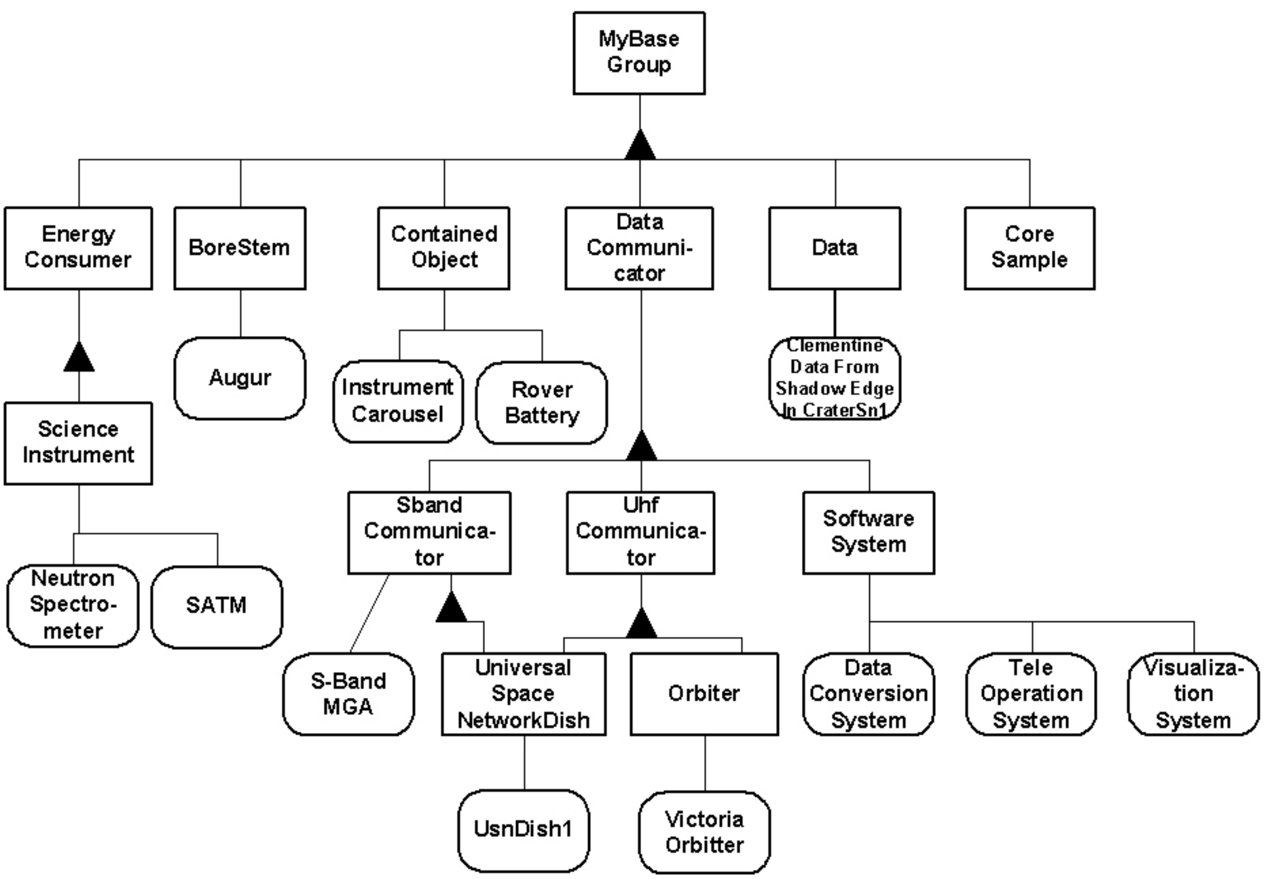

Figure 3. Victoria Object Model

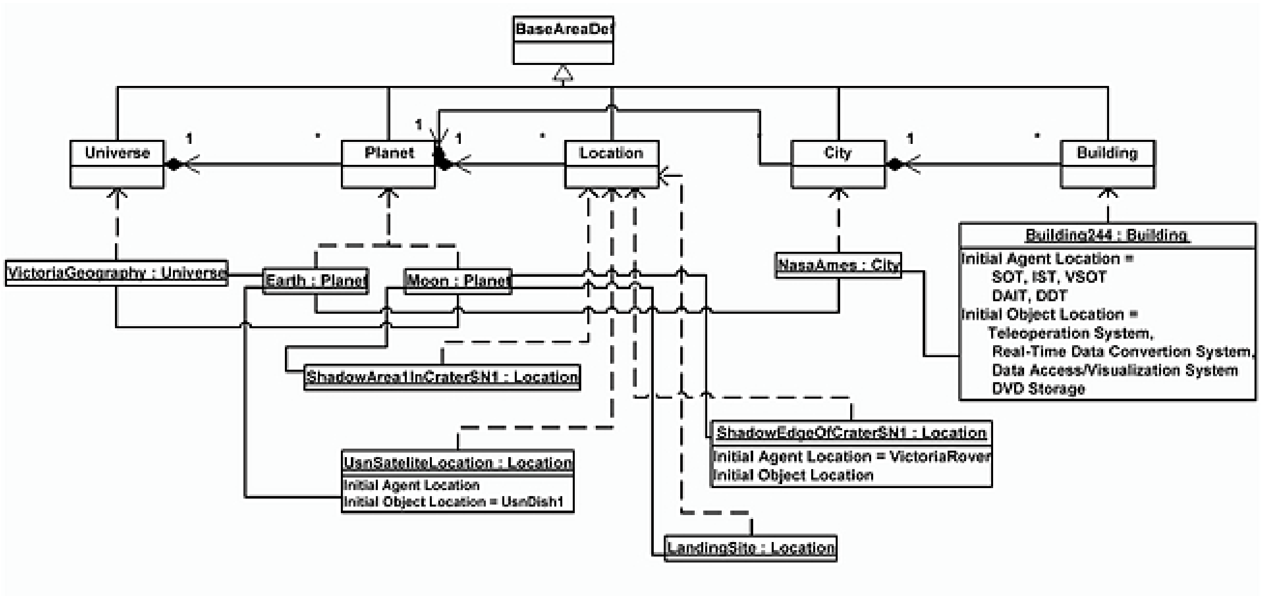

Figure 4. Victoria Geography Model

VICTORIA SIMULATION SCENARIO

The case study selects one of the key surface activities, *searching for water in permanently shadowed craters*:

> The rover has arrived at the shadow edge of crater site number 1. The battery has been fully charged. Based on the data analysis by the Earth-based teams, of the Clementine data available for the shadow edge area of crater site number 1, the science team now decides where to go into this crater and search for water ice. While the rover is traversing into the crater, it is taking hydrogen measurements with the Neutron Spectrometer. When the rover arrives at the assigned location within this crater and it finds hydrogen there, the science team decides it should start drilling 10cm into the surface using the SATM, and collect a 1.0cc lunar sample. When the rover receives this command, it starts the drilling activity and finally deposits the sample into the instrument carousel.

The rover uses two instruments in this scenario: the Neutron Spectrometer (to detect hydrogen—most likely caused by water ice—within the first half meter of the lunar surface below the rover) and the lunar surface drill (Sample Acquisition and Transfer Mechanism —SATM).

The backbone of the simulation model consists of three primary activities: Data uplink, Rover operations, and Uplink.

Data Uplink Activities The scenario starts with the Data Analysis and Interpretation Team (DAIT) retrieving the Clementine data image of the shadow edge area, where the rover is located at the start of the scenario. They review this image using their visualization system, represented in the Brahms model as a VisualizationSystem object. According to the work practice, they do this without anyone requesting that they look at the data. This means that the DAIT needs to know: 1) the location and situation of the rover at all times, 2) whether data is available and needs to be retrieved, and 3) where and how they can retrieve data.

Once the DAIT has retrieved the images, it communicates this to the Science Operations Team (SOT), and they collaboratively analyze these images (the AnalyzeRoverImages activity). When done, the SOT plans the first rover command sequence. According to the scenario being simulated, the SOT decides that the rover needs to drive for a specified amount of time (15 min) into the crater to a specific location (ShadowArea1InCraterSN1), and while driving it should be using its neutron detector instrument to detect hydrogen in the lunar surface. This decision is communicated to the Vehicle and Spacecraft Operations

Team (VSOT), as well as to the DAIT. After this communication, the SOT waits for the rover's downlink data.

Rover Activity. The Victoria rover is modeled as an agent, whereas the neutron spectrometer and SATM instruments are modeled as separate science instrument objects contained in the rover agent. In the scenario model, the Neutron Spectrometer object is active and creates a HydrogenData_1 object containing the hydrogen data that is sent to Earth while the VictoriaRover is traversing to a permanently shadowed area within the crater SN1. The rover then waits for the next command sequence from Earth. During this time the teams on Earth are analyzing the hydrogen data and deciding what to do next. In the Uplink activity, the rover is given the command to search for water ice in the permanent dark area. This eventually triggers the drilling activity, which uses the SATM instrument.

To collect a sample the SATM has to 1) lower its augur to the surface, 2) drill to the depth given as part of the command by the SOT (in this scenario the command says to take a 1.0cc sample at 10cm depth), 3) open the sample cavity door, 4) continue to drill to collect the sample, 5) close the sample door when done, 6) retract the drill from the surface, and 7) deposit the collected sample on the instrument carousel.

In the Brahms model, the Augur object creates the LunarSample_1 object as part of its activity to capture the lunar sample, after opening the sample door and continuing the drilling to collect the 1.0cc sample. The activity times for drilling into the surface are dynamically derived during the simulation.

Downlink Activity. When the rover detects hydrogen in ShadowArea1InCraterSN1 the downlink process starts (represented by the Brahms AgentViewer in Figure 5).[3] The VictoriaRover agent contains the S-BandMGA object, which represents the S-Band transmitter on the rover. The VictoriaRover creates a data object with a) the current rover location information and b) the hydrogen data. This data object is then communicated to Earth, via the UsnDish1 object. The UsnDish1 object communicates this data to the DataConversionSystem, located at NASA Ames. As can be seen in Figure 5, the DataConversionSystem performs two conversion activities, one for the hydrogen data and one for the location data from the rover. The work system design requires that the data conversion system interact with the visualization system without human intervention (details of the data conversion are not represented here).

When the VisualizationSystem receives the newly converted data, the system alerts the DAIT. A member of the DAIT monitors the VisualizationSystem while in the activity WatchForDownlink (see Figure 5). When the DAIT agent detects that there is newly available neutron detector and location data, it retrieves the data from the VisualizationSystem object (the activities RetrieveNeutronData, InterpretNeutronData, and FindRoverLocationData).

Next, the DAIT communicates their findings to the SOT. In the example scenario, the hydrogen data suggest that the rover has found hydrogen in ShadowArea1InCraterSn1. Given this finding, the SOT quickly determines the next command sequence for the rover and communicates this decision to the VSOT (CommunicateDoDrillActivity*)*.

The communication informs the VSOT to transmit the command sequence to the VictoriaRover. The command sequence tells the VictoriaRover to start the SearchForWaterIceInPermanentDarkArea activity. It also tells the VictoriaRover that its sub-activity is to perform the DrillingActivity. Parameters indicate how deep to drill and how big a sample to collect at that depth. Figure 5 shows part of this second uplink process.

The duration of the downlink and second uplink processes determine the duration of the second DoNothing activity of the VictoriaRover, simulating the time the rover is waiting for the Victoria science team to decide the next command sequence.

[3] After the model is developed and compiled, the Brahms simulation engine executes the model in batch mode. A relational database is created, including every simulation event. An end-user display tool (AgentViewer) uses this database to display all groups, classes, agents, objects, and areas in a selectable tree view. The AgentViewer displays an activity time line of the selected agents and objects; communications may be optionally shown via dashed lines between agents and objects.

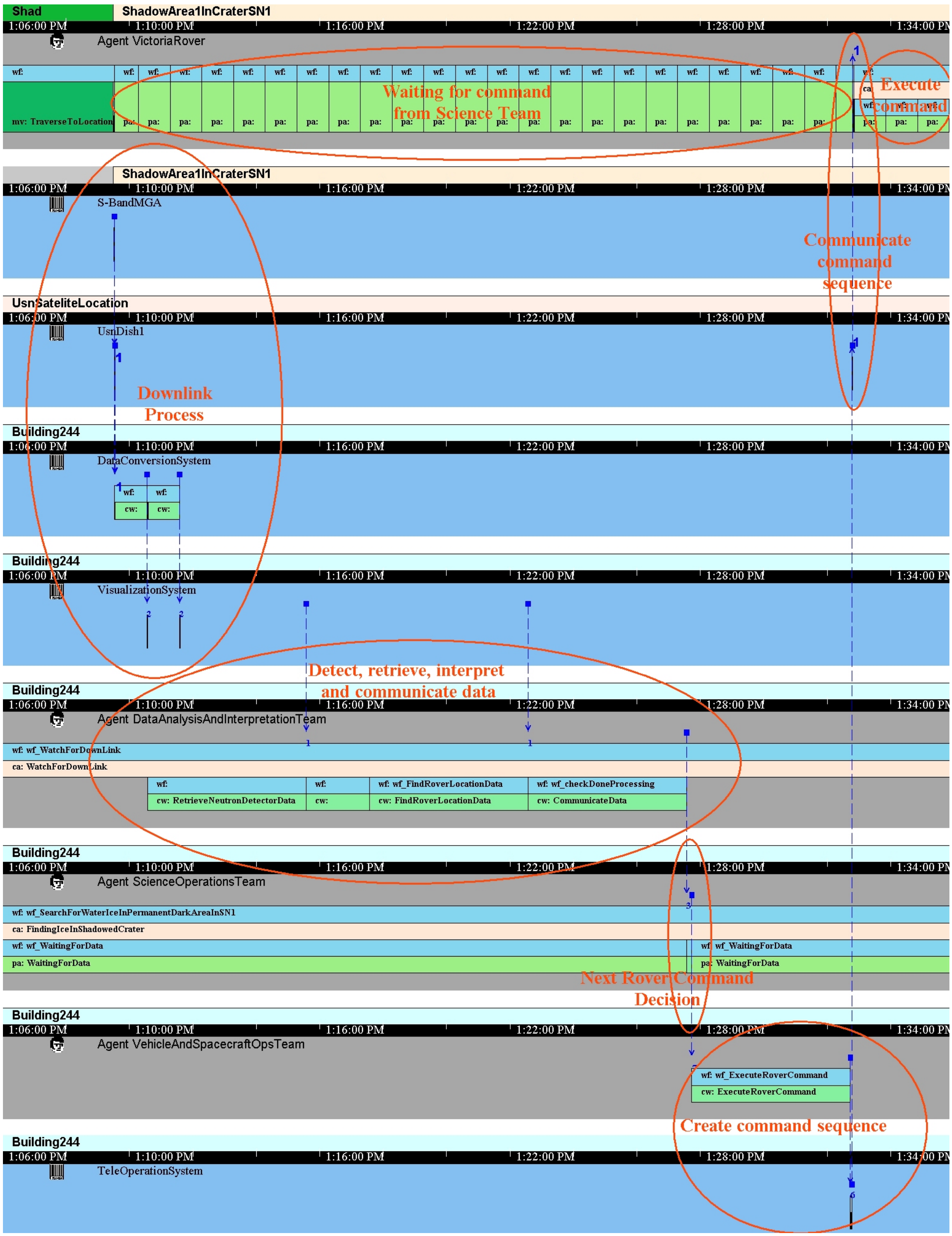

Figure 5. Simulation of downlink and second uplink command activities

USING CONCEPTUAL OBJECTS TO CALCULATE ENERGY USED

To calculate the total energy used by the rover, we need to represent in the model the energy needed for each subsystem during a rover activity. This is done using a conceptual object attached to appropriate workframes. The energy consumption for every rover activity during the simulation of the scenario is shown in Figure 6. In particular, the energy the rover uses during the *Waiting* activity (see "waiting for command from science team" in Figure 5) is defined by the energy needed for *Thermal Protection during driving + Command and Data Handling during driving*. While the rover is standing still and "doing nothing," it consumes power for its thermal protection and its commanding and data handling for its subsystems, such as its processor board.

Besides the power left to use after the scenario, another interesting variable is the energy usage rate by the rover.

$$\boxed{EnergyRate = Total\ Power\ /\ Pbattery(start\ of\ traverse)}$$

Given the energy used in the scenario—drive 900m into the crater, and take one 1.0cc sample at 10cm depth—we calculate that the robot has used almost a third of its power:

$$EnergyRate(drilling\ in\ permanent\ dark\ crater) \approx 0.30$$

This variable represents the rover power consumption effectiveness of the simulated work system design, and is a measure that can be used to compare different work system designs for a model scenario.

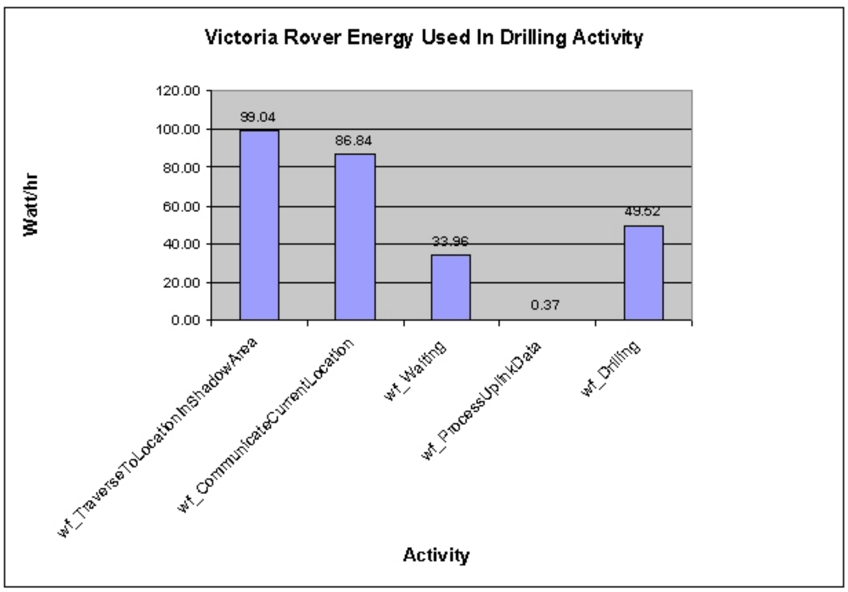

Figure 6. Rover energy used in high-level activities from simulation history database

Limitations of the Modeling Language

We believe that the Brahms language and simulation engine are just in their infancy, with decades of research required before we have accomplished our ultimate objective of modeling the complexities of human behavior in work settings. For example, we need to better represent the nature of identity as played out in interpersonal interactions (e.g., "office politics" and friendships); relate social, cognitive, and anthropometric models; model fatigue, boredom, diurnal rhythm, "external life" (e.g., errands, family interruptions); and model learning (especially by watching and mimicking). We also have practical challenges of developing reusable model components organized by types of settings and human interactions. To use Brahms for exploring a variety of workload conditions, it would be useful to have

tools for statistically generating cases for simulation analysis. More broadly, we require theoretical frameworks for validating analog models (e.g., relating Arctic expeditions to Space Station experience and planned missions to Mars). In subsequent sections, we describe in more detail some of our immediate concerns for modeling NASA missions.

MULTIPLE-DAY SIMULATIONS

All simulations we have constructed to date have modeled behaviors over a few hours at most. In practice, we need to model at least a week of simulated time in order to show the rhythm of life and work. For example, it is common for experiments ("payloads") on the Space Shuttle to require more time than expected, carrying over into multiple days, and changing previous schedules. Understanding and modeling how plans are revised, represented, and communicated is a central part of work practice research. Modeling a Shuttle mission requires modeling 10 to 14 days; a Space Station Expedition lasts for several months; a mission to Mars will require about three years. Although various work-arounds are possible, we believe it will be necessary to extend Brahms to make it convenient and tractable to create long-duration simulations. The key problems are time-indexical beliefs, forgetting, and pattern detection, which we discuss here.

Many beliefs are time-indexical, that is, the meaning changes over time. For example, "the target selected for the rover last week" depends on the current time. Obviously, having a memory of past events is also necessary. Other beliefs refer to intentions, such as "the activity I plan to do this afternoon." In general, a model must be written from the start to allow time-dependent beliefs. For example, "the target selected for the rover" is part of a plan, and the belief must record both the time of this planned event and when the belief was generated.

If agents automatically have beliefs about the activities they perform, the requirements for memory would grow enormously (the effect on performance is less because Brahms uses an optimized reasoning state network). One approach is to declare certain activities as "reflective" (i.e., "cognitively penetrable"), which would restrict what beliefs about activity events (and referenced objects) are automatically recorded.

Forgetting should be simulated. People naturally forget; it is not necessary for the history of all events to be recalled even from week-to-week. Consolidation and abstraction of beliefs is necessary. However, most cognitive research on human memory focuses on how information accumulates, not how it is forgotten. Further, situated cognition theories suggest that remembering is a form of theorizing, not merely retrieving facts (Clancey, 1997). Trends and exceptions are remembered, but not routine happenings, which are blended and "anchored" by early experience. Crucially, forgetting depends on current activities. For example, an agent working on a particular task over several weeks may remember many details from the beginning (suggesting a possible hierarchical scoping effect). Although our interest in developing Brahms is fundamentally on simulating interactive behavior and not learning or reasoning per se, we must incorporate a model of memory if we are to simulate behavior over multiple days.

Repeated experiences should influence subsequent behavior. A simulated agent should not "mindlessly" repeat behaviors. People notice patterns and break out of loops. Also, people get bored or tired if forced to repeat behaviors. Pattern detection in experience (e.g., "This is the same process that produced an error yesterday") plays an essential role in learning, plus repetition implicitly influences motivation and level of attention. At another level, social theories of learning suggest that people learn by mimicking others (so co-located workers tend to learn about each other's jobs). Further, people develop relationships with each other, influencing their interest to assist each other, by being co-located. One simple approach to modeling learning of this sort is to have interactions between individuals in particular situations lead to an exchange of behaviors (workframes are exchanged). This is a straightforward application of existing work in cognitive science, with the proviso that we do not interpret this "transfer of expertise" literally, but view it as a modeling that people learn from each other. Furthermore, although much of cognitive science is concerned with modeling human learning, very little research has *modeled*

learning behavior as interactive, interpersonal, and resulting from patterns detected gradually and incidentally.

MISSIONS, SCHEDULES, AND VEHICLES

In developing Brahms simulations, we have not previously emphasized the static class-instance descriptions one finds in conventional knowledge models (such as expert systems). However, such representational constructs are needed to describe mission and expedition scenarios as relationships between Brahms model components. For example, the work in a Victoria mission involves multiple shifts (a particular role is fulfilled by different people during the day), vehicle trajectories, and timelines of activities. More generally, a space mission scenario involves a description of groups, locations, objects, and activity plans (e.g., a Shuttle mission). Further, locations (of the Shuttle) and group membership (crew of the Shuttle) change during the course of a mission (e.g., exchanging crew members with the Station). Neither these static nor dynamic features have been adequately incorporated in the Brahms language. The notion of a "conceptual object" in Brahms (originally included to allow representing "job orders" in office workplaces) could be extended to dynamically represent a configuration of groups, agents, objects, locations, and time-stamped activities. Clearly, the notion of a *schedule* is basic and needs to be represented conveniently using an interactive, hierarchical editor (not as a list of beliefs). Some basic constructs are outlined here.

LOCATION-GROUP (LG): the people who occupy (live or work in) a certain location at a certain time. Notice how the groups in Victoria are idealized because they are defined by function, which is location independent. In contrast, consider the group, "people living and working in the Mars Arctic Research Station" (Clancey, 2001). This group changes during *phases* of an *expedition*, and may include a visitor on a particular day. Further, the location of an LG may change, such as "people living and working in the Space Station during Expedition 3"—the location of the Station changes every moment. Brahms currently provides no method for changing group membership (let alone the location of a building) during a simulation. In our original focus on office work, organizational changes were infrequent. In retrospect, we realize that office meetings and other projects are improvised during daily work and require the same capability to represent both planned and dynamically modified group membership.

SCHEDULED ACTIVITY-GROUP (SAG): a planned LG, e.g., a rotation or phase during an expedition, a particular Shuttle mission. More formally, a SAG is a *group* planned to engage in a particular *activity* at a particular *location* (or trajectory) for a certain *duration* or on certain start and end times. SAGs may be hierarchically nested, as a phase (with particular members) during an expedition. For example, "Clancey was a member of Rotation #2 inside the Arctic Research Station from July 8-17 during the Haughton-Mars Expedition for the 2001 field season." SAGs may be planned, active, or past. SAGs often occur in a series, such as shifts for work day, which may or may not overlap. Group roles repeat during every SAG in a series (e.g., each Station crew has a commander). Agents may be *temporary members* of a planned SAG, e.g., a visitor on the Station during an expedition. A SAG usually has planned (and often written) activities on a timeline (a *schedule*).

LOCATION-OBJECT (LO): objects in which people live, whose location changes over time, e.g., the Space Shuttle, a "Transhab" spacecraft for going to Mars from Earth, a pressurized Rover on Mars. Brahms development originally focused on office work in cubicles; in shifting to NASA's world, we must model vehicles, space bodies (planets, satellites), and trajectories. Objects in space have combined properties, some of which change over time. For example, the Space Shuttle is a *vehicle*, which becomes a *spacecraft-in-orbit*, which is a *satellite* that is a *habitat*. Our original notion of Brahms geography model as consisting of rooms in buildings in a city seems humorously simplistic. In effect, some Brahms objects must be also "area definitions," such that agents and objects can occupy them. This extends the object-oriented scheme to the geography model, so spaces such as rooms and buildings (and especially habitats and spacecraft) are modeled as three-dimensional objects with attributes and behaviors.

A NASA mission can then be defined as a SAG associated with one or more LOs. For example, mission STS-104 involves a Shuttle crew (a group), a particular Shuttle Vehicle (object), a Trajectory Plan (a kind

conceptual object?), and Activity Plan (which might involve the Space Station). Victoria is a mission involving many teams, a rover, trajectories on the moon, and an activity plan for several months of lunar surface operations.

HUMAN BODY MODEL

In practice, where agents perform an activity partly depends on available space and tools. For example, an crew member in the Mars habitat may read in his/her stateroom if there are no comfortable chairs available. So modeling the activity of reading involves modeling chairs, a resource the agent requires. Similarly, the simulation display must be realistic, so the agent has a different visible posture when sitting in a chair. Further, the agent's zone of perception must relate to posture (e.g., standing on a ladder in the Mars habitat, one can look into the tank of water above the staterooms and determine the amount of water available). Here is a basic outline of considerations.

- Postures
  - Agents have postures, e.g., sitting, standing, lying down.
  - These postures occur on some surface or object, e.g., sitting on a chair, standing on a ladder, sitting on the floor.
  - Body posture is oriented with respect to other objects, e.g., facing someone else, facing the galley sink.
  - Postures may be composed: sitting at a table (by sitting on a chair that is next to the table).
- Zones of perception
  - Line of sight, e.g., facing the galley sink, an agent cannot see who is standing on the ladder; looking outside the West portal, the agent can see the airport runway
  - Within earshot, e.g., a whisper on the lower deck cannot be heard on the upper deck
- Moving with someone or something
  - An agent or object follows (or keeps constant distance from) another agent or object, e.g., the Robotic Assistant moves with the astronaut, the crew member follows the commander in the EVA preparation room.
- Carrying contained objects
  - Contained objects are brought along, even when the agent doesn't know what is inside, e.g., a robot carries a box and the contained objects change their location, too.
- Incremental movement
  - Movement is discrete, so the agent/object is located at different places along a path over time.
  - Interactions may occur between the agent and the objects in the environment during the movement (e.g., having a conversation with someone you encounter).
  - Movement may be hindered or varied in speed by other objects in the environment (e.g., someone else is on the ladder, so you must wait for them to go up or come down).

OTHER FACTORS NOT CONSIDERED IN BRAHMS

In the 1970s and 80s, cognitive scientists commonly said that "the model is the theory"—the simulation embodied all of the factors and principles they understood to be relevant to human cognition. Such claims were especially possible because psychologists and artificial intelligence researchers almost unanimously assumed that textual components (e.g., "frames" or production rules) in simulations mapped onto physical structures in the human brain (e.g., an expert system rule not only represented an expert's knowledge, it was how knowledge was stored in the expert's brain). However, in Brahms we emphasize that we are modeling behaviors and not knowledge per se, so there is no necessary relation between

Brahms constructs and how the brain works. As we incorporate aspects of memory and learning, we must of course make such commitments; but even then we will not suppose to model how memory works, only its behavioral effects.

The distinction we have drawn represents a significant shift in how models are interpreted. Most importantly, we can now list many theoretical notions that are not embodied in Brahms models. The model is a pale reflection of our understanding, but hopefully a useful tool for designing work systems and training. Beyond the representation of memory, learning, perception, and postures, we have not worried about other well-known factors in human behavior, such as hunger and fatigue. We have not incorporated anthropometric models of reach and line of sight (e.g., sitting in a chair can a person reach a control switch?). At another level, we have only begun to model social relations and their effects.

Crucially, a Brahms model is not based on traits, in which "properties" of people interact. Rather, we model and study how *behaviors* interact in a simulated environment. Trait-based models parameterize behaviors through isolated properties (e.g., Bill is friendly) and state rules for how they influence agent behavior (e.g., two friendly people have longer conversations). In Brahms, such attributes would be represented as *relations* (e.g., Bill is a friend of Maarten) which conditionally influence behaviors (e.g., If you need help and agent X is your friend, communicate with agent X about your needs). Emphasis is thus placed on who knows whom and what people know about each other, rather than isolated attributes (e.g., an agent's skills). Modeling relationships, their influence on work practice, and how relations and behaviors change over time is a major research area for Brahms-like simulations.

To summarize well-known aspects of human behavior that are not modeled in Brahms:

- *Actual language* used by agents when communicating (e.g., how social conversations become task oriented)
- *Learning* by watching others or being told how to do something.
- Agents' *models of their history and trends of their group*: history of the group, competitive pressures, management's initiatives, changes in customers.
- *Cumulative effects of work flow*, especially the effects of continued interruptions and waiting (also: forgetting, variety, rhythm, fatigue, anxiety, exuberance).
- *Reconceptualization* (learning on the job) influencing later priorities, attitudes, judgments in handling difficult situations
- *Complex juggling and simultaneity of activities* to ensure closure, to be productive (e.g., reading while on the phone).
- *Life away from work*: breaks, vacations, family.

Each model we construct is an experiment and a revelation. Every setting changes our understanding of work practice and the requirements for modeling it. The practical boundaries of what is necessary for work systems design and what is only of research interest remains to be seen.

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Ten Commandments for Modelling and Simulation Fitness for Purpose

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ABSTRACT: *Decision makers need confidence that models and simulations are fit to support their decision making process, such that their decisions are useful to their specific project or program. Current validation & verification (V&V) methods seldom give an inclusive and widely understood 'happy' feeling about the credibility of a model, simulation or constituent component. Discussions between collaborating partners concerning what exactly is the measure of 'realism', credibility and 'fitness for purpose' whilst discussing the coverage of V&V evidence can be very distracting and ultimately use up expensive program time. This paper seeks to identify the Top Ten reasons why models and simulations are or become unfit for purpose, from some original research. Further, to invert the negative logic of 'unfitness' to derive "Ten Commandments for Modelling and Simulation. This could ultimately lead to more credible models being more fit for purpose, which would benefit all stakeholders as well as reducing the need to repeat validation and verification exercises.*

1. Introduction

Advances in low cost, high power computers, graphics and networking telecommunications advances are now providing the opportunities to use distributed models and simulations in new and exciting ways. It is becoming imperative that there is confidence in the models used, such that useful decisions can be made when regarding the output from such activities. Having a common understanding from which to discuss ideas of Fitness for Purpose is a very important challenge for continuing progress in this field.

This paper is organised as follows: Section 2 introduces Fitness for purpose and Credibility. Section 3 details the research methodology for this study. Section 4 presents the identified Top Ten reasons for being unfit for purpose in an influence diagram. Section 5 introduces Goal Structuring Notation and its use in inverting negative influence diagrams. Section 6 presents The Ten Commandments of Modelling and Simulation. Finally, section 7 summarises the findings and draws some conclusions.

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2. Fitness for Purpose & Credibility

Credibility can be said to be concerned with the assurance that models and simulations are appropriate representations of the real-world system being studied [1]. Fitness for Purpose can be said to be concerned with suitability and confidence. The two descriptions are closely linked together – however, Credibility is more linked to the 'product' that is the model or simulation, Fitness for Purpose focuses on the (potentially) many uses of the product.

Assessing Fitness for Purpose is a difficult challenge, but is still required such that the degree of confidence in the behaviour and outputs of the simulation may be determined. The user will treat simulation results as credible (i.e. the simulation as 'Fit'), when there are enough indicators, arguments and evidence that demonstrates that it fulfils its intended purpose [2]. These credible arguments and evidence are required so that useful decisions can be made about the system of interest.

Accepting the statements above, there is still the question of what exactly does one need to check for when assessing the Fitness, Credibility or quality of a model or simulation. Concepts for Verification and Validation offer very useful indicators and methods. These include validating the concept, verifying the design and implementation and validating results [3]. Assuring quality (of simulations) involves the measurement and assessment of a variety of quality characteristics [4]. It is still difficult to find ideas and explanations of this *variety* of areas needed to review in order to satisfy Fitness (or quality) requirements.

3. Research methodology

Excellent ideas and opinions about why models are unfit are held within the minds of many specialists across the defence industry. The Modelling and Simulation Technical Managers Forum at QinetiQ (formally DERA) had the opinion that the international community would benefit by having some of these ideas shared. The more common principles and guidance for avoiding un-fitness (and thereby promoting fitness) could then be studied.

A series of workshops were held where invited subject matter experts from across the UK defence industry were asked to present, discuss and develop their 'Top three' reasons why models and simulations were or become unfit for purpose. The delegates were asked to link together their ideas using the Fault-tree influence diagram layout. The Fault-tree output is a particular type of an influence diagram. It is particularly suited to describing a sequence of uncertain events that affect the probability that some event of interest occurs [5]. The delegates were encouraged to consider the causes that would lead to their ideas, and also the consequences of them. In this way they built more inclusive influence diagrams themselves using their tacit knowledge. The delegates were also asked to consider what the top event of such a diagram would be.

From all the workshops, the sets of top three ideas were analysed, compared and eventually combined to produce a 'Top Ten' of reasons for unfitness. These were then developed into a new influence diagram showing their cause and effect links. The generated ideas and influence diagram are presented in the following sections.

4. The TOP TEN reasons for unfitness

The most commonly highlighted areas from the workshop experts were as follows[6];

1 People do not have enough relevant experience.
2 Evidence does not support a fitness argument.
3 Development process is wrong for the purpose.
4 Configuration management is unsuitable for the purpose.
5 Lack of recorded assumption information.
6 Data sets used in the model are inaccurate.
7 Incorrect level of modelling resolution.

8 People do not have enough training.
9 Data set is not coherent with the purpose.
10 Evidence of fitness is missing.

From the workshop-derived influence diagrams and the author's own work, a more inclusive influence diagram was constructed from these ten ideas, and is shown in Figure 1.

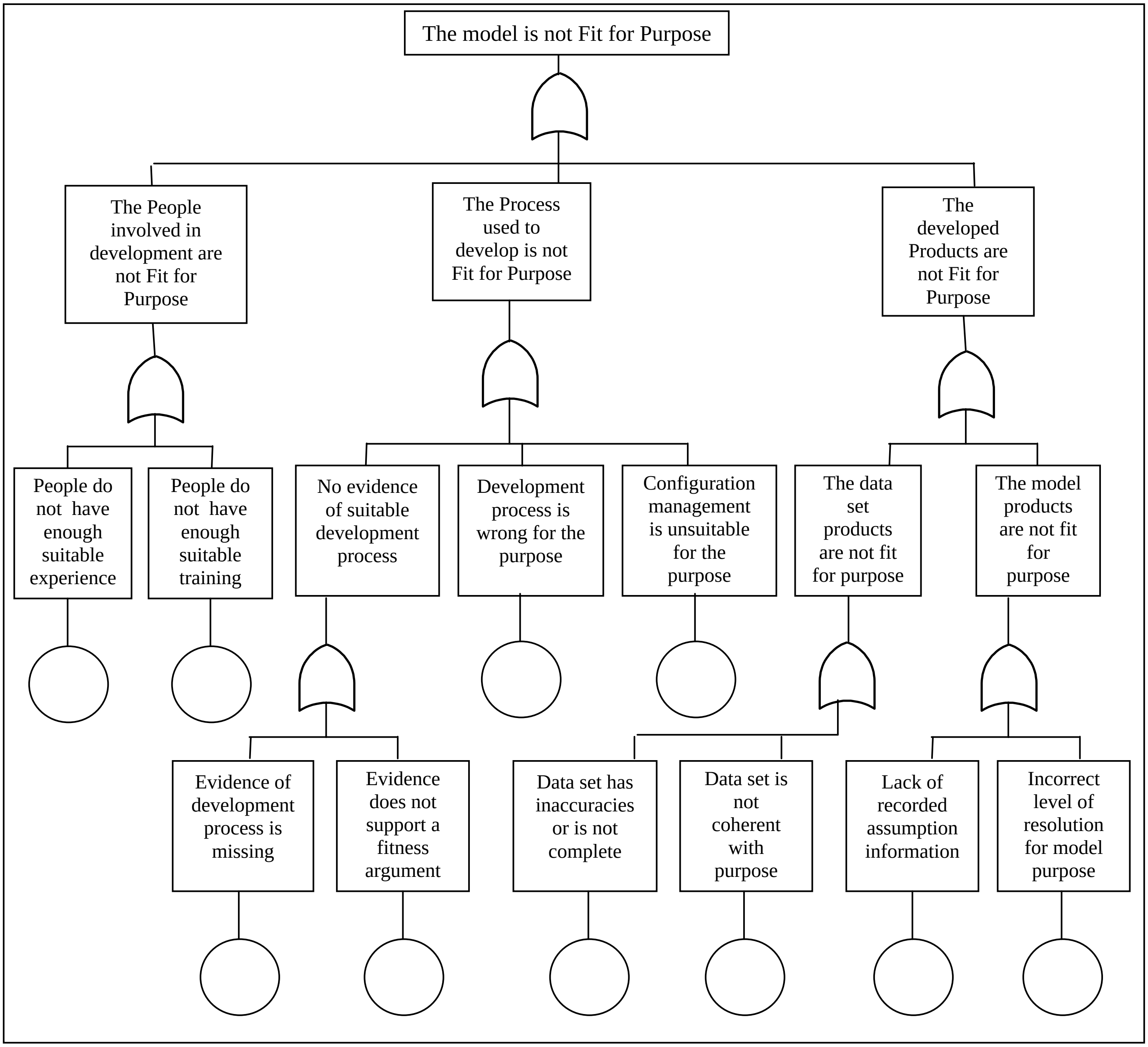

Figure 1. Fault-tree diagram combining the Top Ten reasons for being or becoming unfit

Of course, this diagram is not complete – it just brings together the relationship between the ‘big’ reasons identified during the workshop process. Each ending box could be developed further in order to study in more detail the particular reasons why those events occur, but this is beyond the scope of this paper. The ten reasons for being or becoming unfit naturally fell into three distinct groups – People, Process and Products. The ‘people’ grouping covers the idea that the analysts are untrained and that the people are not ‘fit for purpose’. A fool with a tool, is still a fool, unless he is trained to use the tool properly. The ‘development processes’ directly captures the idea that the modelling process was incorrect or inappropriate. It also can be seen as the reason why the implicit knowledge and assumptions had not been identified – the development process didn’t include this as a requirement, perhaps. The ‘model product’ group captures the ideas of incorrect level of resolution and the idea of inadequate data.

5. Goal Structuring Notation

The idea of using negative logic to promote positive actions has been around since Biblical times – consider for a moment the structure and purpose of the majority of the Ten Commandments. One method of accomplishing this in this case is to invert the negative logic and produce a system based on attaining positive goals. A formal structure for this does exist – Goal Structuring Notation (GSN). This is a structured method for developing and presenting complex arguments in a hierarchical format. Positive goals are stated, a strategy to attain that goal is described, and finally a solution is defined. This can go on over many levels – as many as is needed to describe and satisfy the argument. So sub-goals can support strategies, which can lead to sub-strategies to concentrate on a particular area if required, and so on. Assumptions and contextual notes are encouraged to give a more complete structure to the overall argument. For more detailed information on GSN see ref. [7].

In the case presented in this paper, GSN can be used to generate the positive-focussed structure which can be used to develop The Ten Commandments of Modelling and Simulation. The Fault-tree top event was ‘The model is NOT fit for purpose’, the inverse would simply be a goal of ‘The model is fit for purpose’. The next step of the inverting method is to select a strategy to accomplish the goal. Some direction can be obtained from the Fault-tree diagram. The Fault-tree considered the ‘branches’ of People, Product and Process, so our GSN top strategy should likewise follow this pattern. The strategy could be ‘(The top goal can be satisfied by a…) Strategy of ensuring the Fitness of People, Product and Process’.. As an example, the three branches from the Fault-tree are now separated out and shown in Figures 2 to 4 with the corresponding developed GSN diagrams.

The concept of developing an appropriate strategy is very important – not only to the structure of GSN, but also to the completeness of the argument. During the inversion from Fault-tree to GSN the logic of the Fault-tree gates is lost. There is no facility for these within GSN. The strategy description in GSN takes on the role of the logic gates, but also allows a much greater expression of intent. The software product behind the display of GSN allows unlimited textual notes ‘behind’ the appropriate box to explain the description in the box, provide referenced documents and even hyperlink direct to them if required.

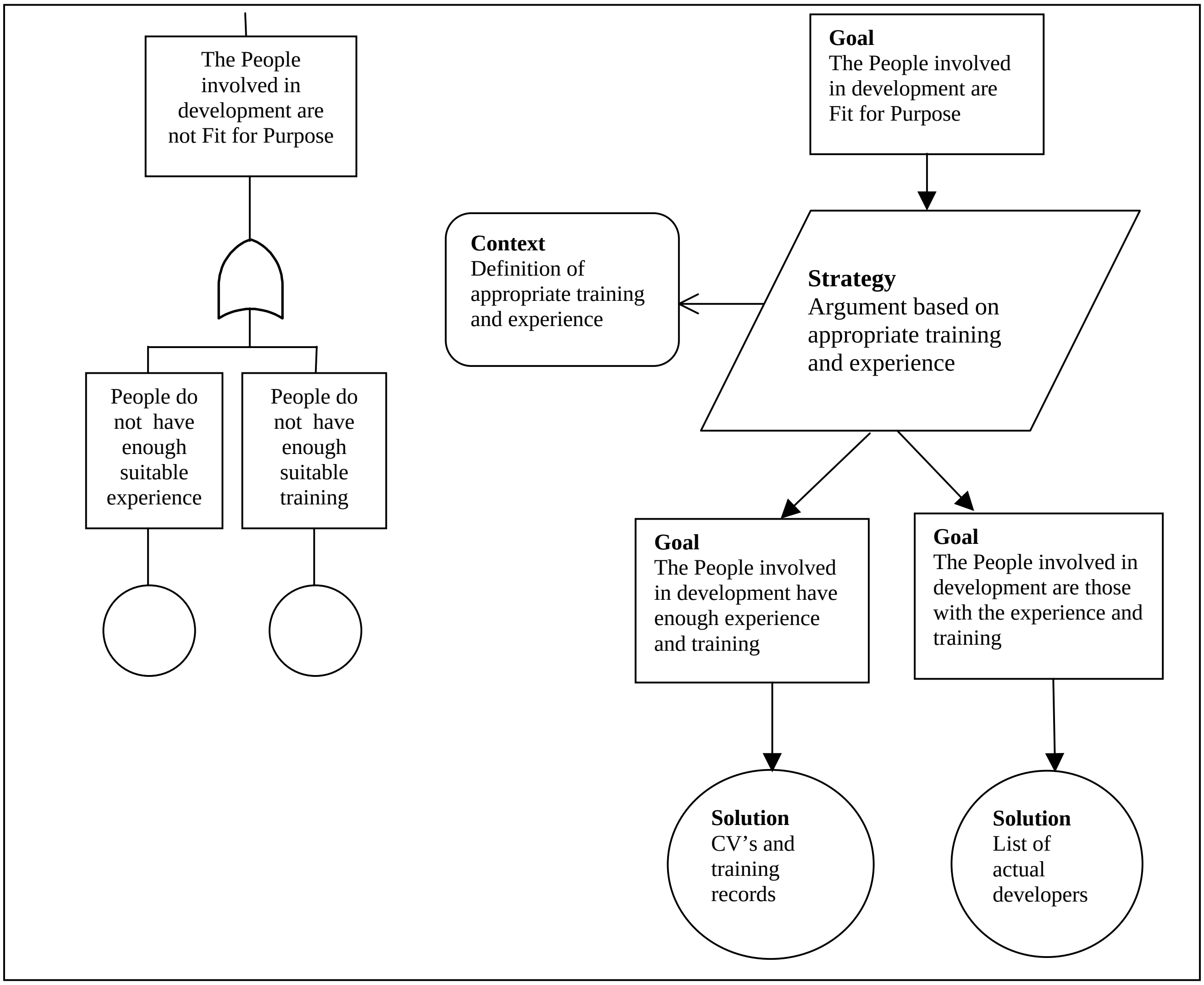

Figure 2. Derivation of GSN from Fault-tree on People.

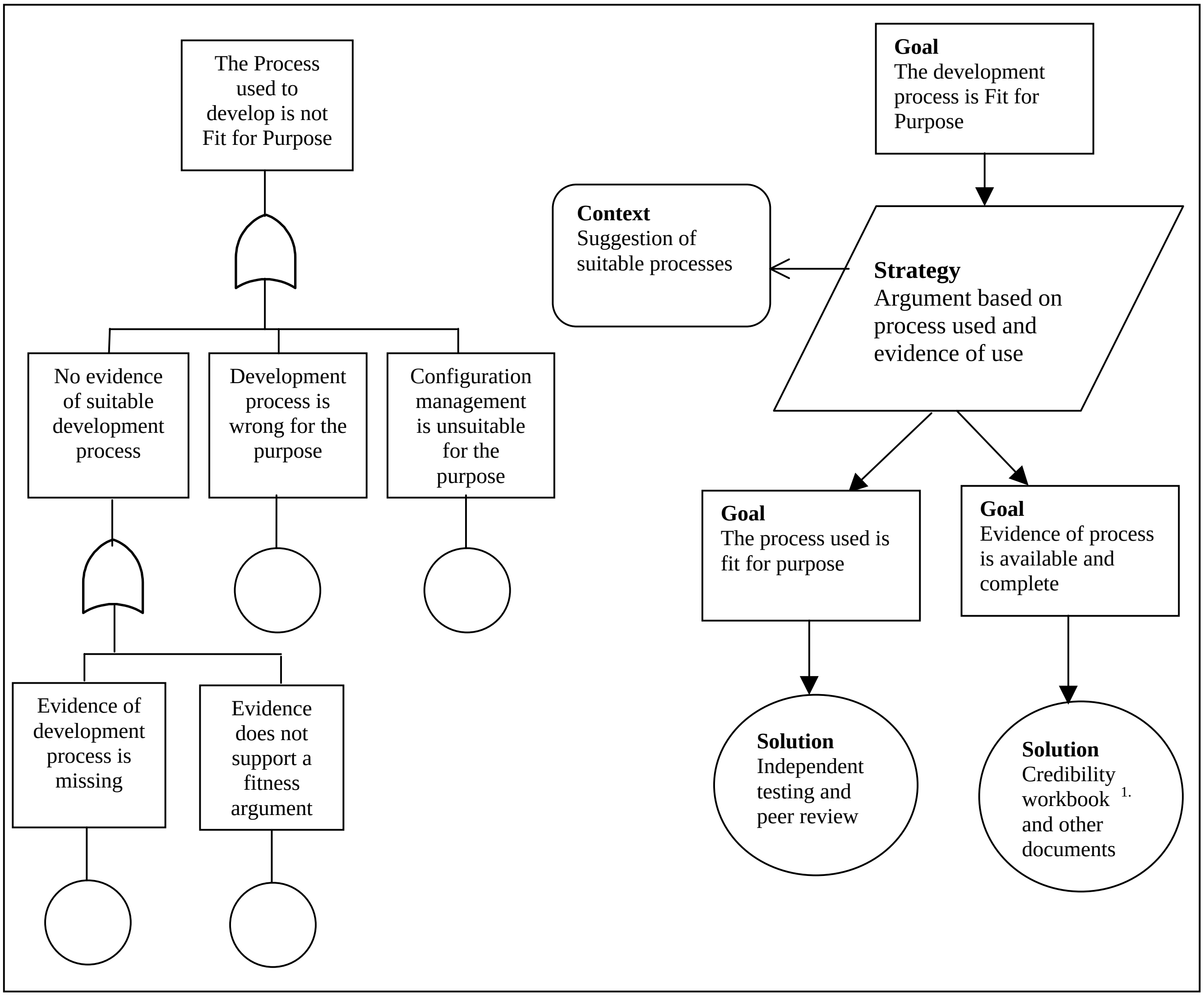

Figure 3 Derivation of GSN from Fault-tree on Processes

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1. A new NATO International Test and Operating Procedure (ITOP) document is currently being produced by a working group of experts from the UK, USA, France and Germany. It recommends the use of a structured, evidence-based argument for the Verification and Validation of Models and Simulations. It should also be able to maintain accurate configuration management. The collection of evidence to be presented will be known as a Credibility Workbook. For more information on this NATO document see ref [8].

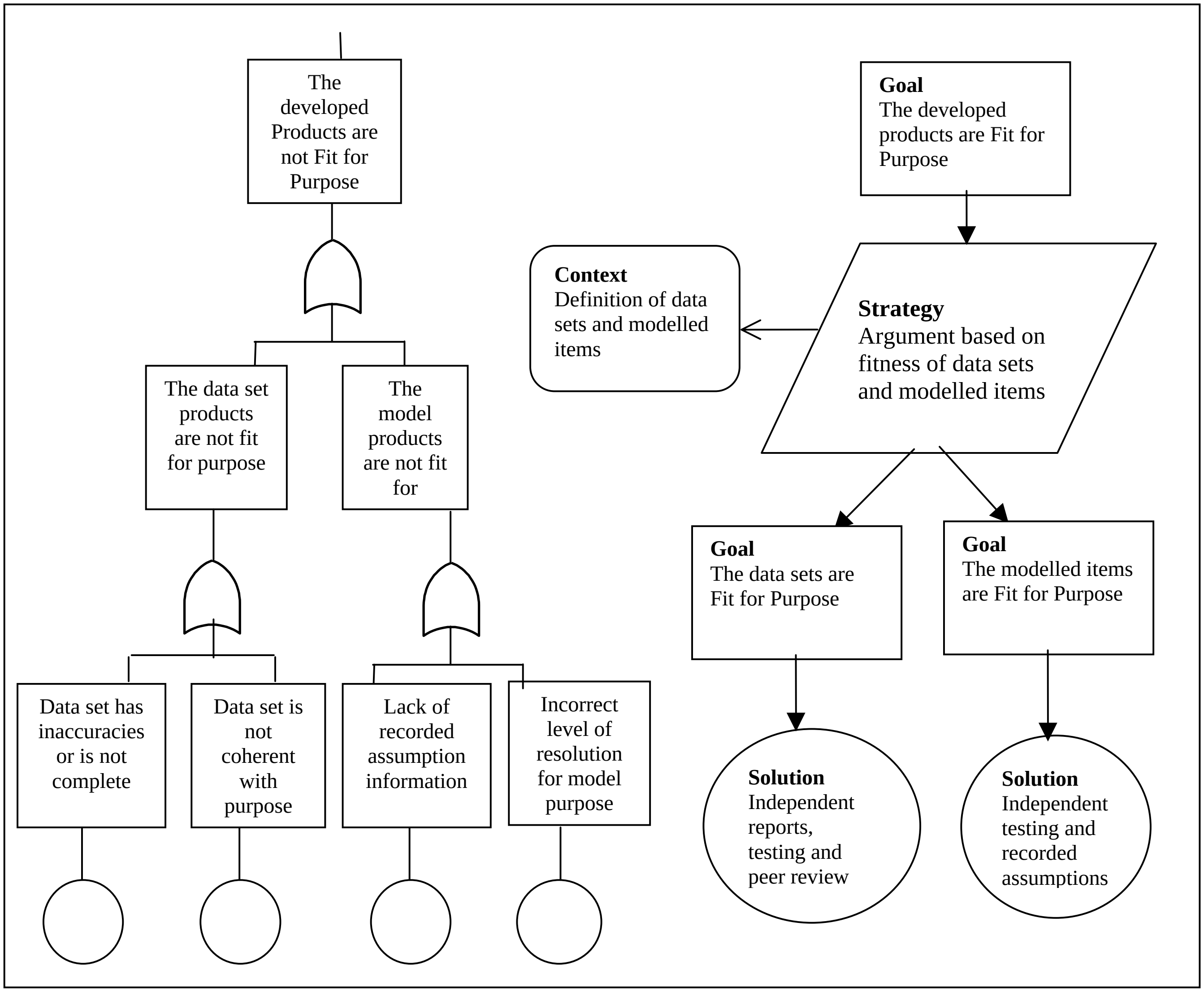

Figure 4 Derivation of GSN from Fault-tree on Products

As can be seen from a comparison of the three sets of diagrams, the Fault-trees indicate what events have gone wrong, the GSN indicates how to attain goals of events going well. The GSN also has the facility to indicate ‘Solutions’ that will satisfy the (sub) goals and ultimately lead to a successful top event.

These GSN diagrams are suggestions form the authors work and experience – they are not intended to be full and complete. Other users in their own fields, with their own requirements can determine for themselves exactly what should be written in the Goals, Strategies and Solutions.

6. The Ten Commandments of Modelling and Simulation

From the inversion of the negative bias of the Fault-tree influence diagrams, a more positive Goal driven structure can be derived. In this paper the purpose was to carry out this inversion to obtain ten instructions, or commandments, such that some of the greater challenges of proving fitness, Credibility and confidence in a model or simulation may be overcome. Below is presented the QinetiQ Ten Commandments of Modelling and Simulation.

1. **Understand the purpose of your model or simulation and re-check it often.**
2. **Train your people to the most appropriate level for their tasking.**
3. **Keep records of who did what and when.**
4. **Record your assumptions about reality and your model and simulation during its development.**
5. **Review the validity of your assumptions as development and use progresses.**
6. **Ensure data sets are valid, including input sets, testing sets and mathematical constants.**
7. **Carry out as much Validation and Verification as necessary.**
8. **Obtain independent checking and peer review of your work (if appropriate).**
9. **Collect, manage and maintain your evidence in a structured way.**
10. **Record system development in a Credibility Workbook.**

Remember:- GOAL – ARGUMENT – EVIDENCE.

7. Summary

Whilst Credibility and Fitness for Purpose are not absolute metrics, there is a need for a greater understanding of actually what makes up these measures. This is not an easy challenge to undertake, many textbook discuss this at length[3],[5]. This paper asked subject matter experts for their opinions on the reasons why models and simulations do not have Credibility or Fitness. The results from this research have been presented in a negative and positive influence diagram, and have indicated three categories which can be used to discuss the metrics – People, Products and Processes. The paper then derived the first influence diagram from the generated ideas, and utilised the Fault-tree format.

The inversion of this negativity was shown to be possible, and in this case it was used to produced Ten ‘Commandments’ which will allow practitioners to focus on the top ten areas where Credibility and Fitness are greatly affected. The new structure produced was in the form of a GSN diagram, which although still a ‘young’ idea, has allowed an innovative view of how one might overcome the challenge of proving Credibility and Fitness for Purpose.

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A Methodology for Verification and Validation of Models and Simulations: Acquirers' View Point

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Summary

The most challenging and common problem of the acquirers of the M&S is the assessment of the acceptability of an intermediate / end product of a model / simulation development. The objectives of this paper are to propose a methodology to be followed by the acquirer for verification and validation of the intermediate / end products to be developed, and to present the observations obtained from the experimentation on this proposed methodology. The acquirers who lack of knowledge about the verification and validation, specifically, of the models and simulations are the targeted audience of this paper.

The proposed methodology is a road map for the driver who drives his/her car on the modeling and simulation roads. This road map may only help the drivers to find an appropriate direction to his/her destination. The driving conventions are left to the driver himself / herself.

Introduction

For new development models and simulations, the acquirers usually have problems with assessing the acceptability of the intermediate and end products. The solution is the verification and validation of the products during development.

The literature survey shows that the intermediate products of a model / simulation development can be verified and/or validated by means of verification and validation techniques.

However, the methodologies encountered in the literature, generally reflect the developer's perspective, and require intense Software Engineering and/or Operations Research background with knowledge about the verification and validation techniques which acquirers may not be familiar with.

The goal of this paper is to propose a methodology

- That is adequate to assess the acceptability of the intermediate products.
- That the acquirer can focus on the issues based on his/her needs,
- That does not require an intense educational background on Software Engineering and / or Operations Research with knowledge about the verification and validation activities,
- That is straightforwardly applicable in reasonable time duration.

The proposed methodology is,

- Independent from the types of models / simulations,
- For new development and standalone models and simulations,
- Addresses the early phases of the development,
- Product focused,
- For the acquirers to perform verification and validation activities by themselves.

There are more than 100 verification and validation techniques in the literature [1]. I choose the techniques that are appropriate to the profile of the acquirer, from the informal, static, and dynamic techniques [1,2]. The formal and special techniques that require intense Software Engineering background are excluded from this methodology, such as induction, lambda calculus, class firewall technique, and object state technique. Among the other techniques, I selected nine techniques as easily applicable by the acquirers.

I examined the methodologies and techniques from the perspective of the verification and validation. I found that the acceptability of a product is generally based on three accuracy indicators [2,3,4,5,6,7], as shown in the Figure-1. These accuracy indicators are:

- Transformational accuracy that concerns with the behavior, input, and output of the model / simulation,
- Structural accuracy that concerns with the correctness, completeness, consistency, and traceability of the model / simulation,
- Interface accuracy that concerns with the interaction between the user and the model / simulation.

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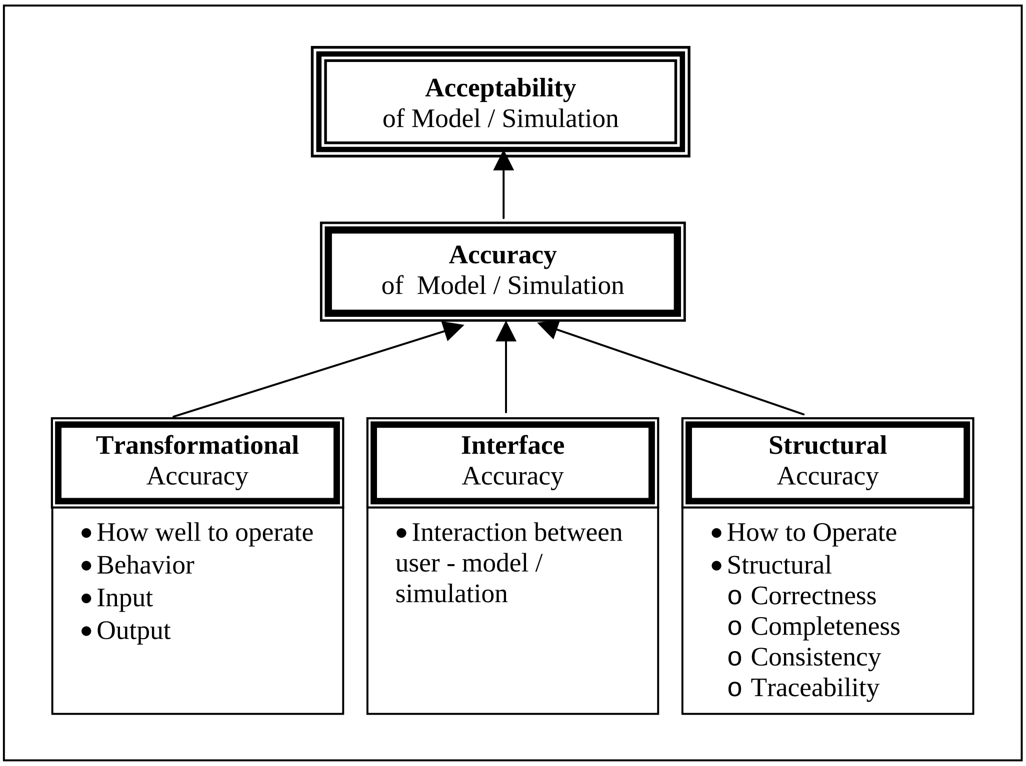
Figure-1. The Accuracy Indicators.



I tried to match these accuracy indicators with the verification and validation techniques, as shown in the Table-1. As a result,

- The informal techniques can be used for all accuracy indicators,
- The dynamic techniques can be used for only transformational accuracy,
- The user interface analysis can be used for interface accuracy,
- Traceability assessment can be used for structural accuracy.

Table-1. The Relation Between V&V Techniques and The Accuracy Indicators.

No.	**Type of Technique**	**Name of Technique**	**Transformational Accuracy**	**Interface Accuracy**	**Structural Accuracy**
1	Informal	Face Validation	X	X	X
2		Inspection	X	X	X
3		Review	X	X	X
4		Walkthrough	X	X	X
5	Static	User Interface Analysis		X	
6		Traceability Assessment			X
7	Dynamic	Sensitivity Analysis	X		
8		Comparison Testing	X		
9		Functional Testing	X		

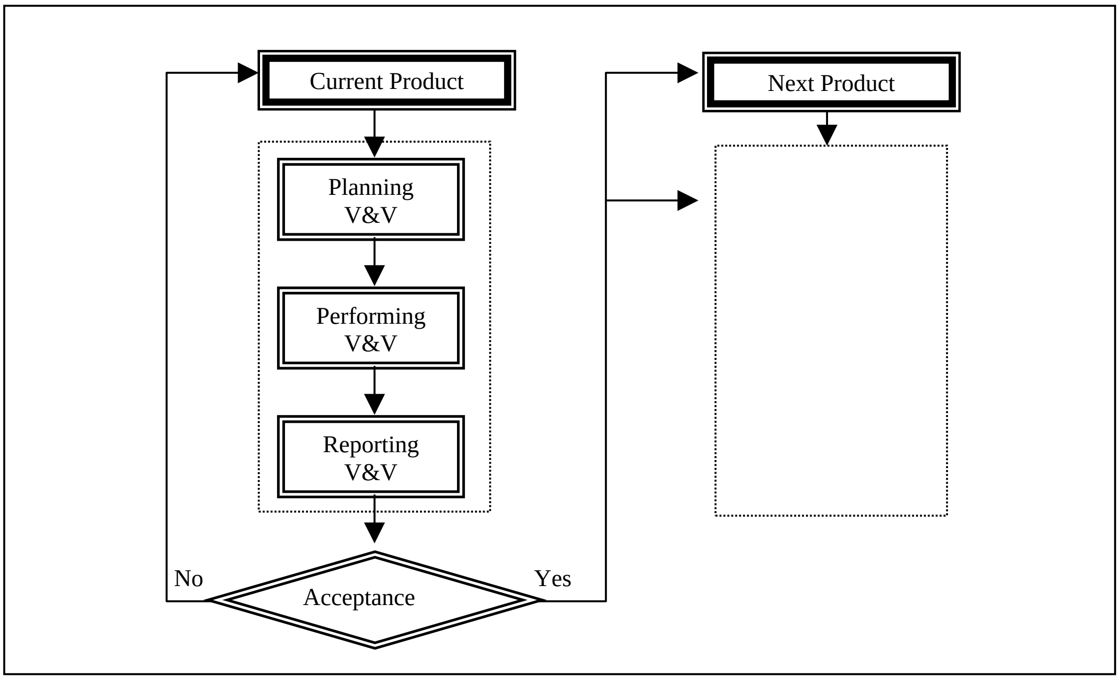
Methodology

The acquirer performs verification and validation activities at the end of each phase of the development process, and makes a judgment about whether the development may progress based on the assessment of the acceptability of the intermediate product. If the intermediate product of that phase is not satisfactory and

unacceptable by the acquirer, then the developer repeats the same phase to resolve the issues, till the acquirer is satisfied with the product.

The proposed methodology includes three-step process for verification and validation of each intermediate product, as shown in the Figure-2.

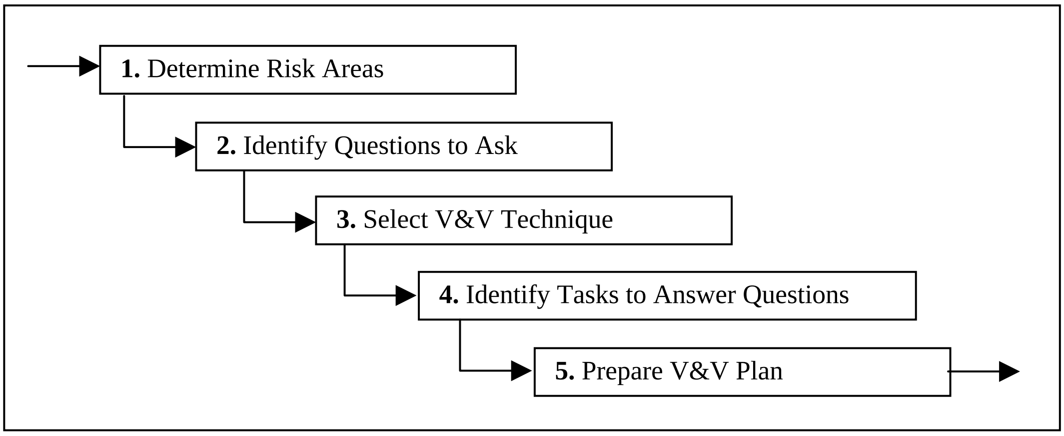
Figure-2. The V&V Process for an Intermediate Product.



The first step, planning verification and validation, deals with the how to perform verification and validation, which tasks to perform, by whom, and in what schedule. The second step, performing verification and validation, includes the execution of the tasks specified in the verification and validation implementation plan prepared at the first step. The last step, reporting verification and validation, enables to define how to report the results of the verification and validation activities performed. The three-step process is repeated for the next product. The results and reports of the previous verification and validation activities are used in the next iteration of the process.

"Planning Verification and Validation" step consists of five tasks that are performed sequentially: determine risk areas, identify questions to ask, select verification and validation technique, identify tasks to answer questions formed, and prepare a verification and validation implementation plan, as shown in Figure-3.

Figure-3. Process of Planning V&V Activities.



I defined the risk for a product as the undesirable weakness in that product. The risk area is the vulnerable part of the product. The acquirer is to determine the vulnerable parts and the risks for that product. The sample risk areas created based on the verification and validation techniques and checklists in the literature [3,4,8,9,10,11] are given in Table-2.

Table-2. Examples for Risk Areas.

Vulnerable Part	Vulnerability / Risk
Documentation	• Ambiguity, inconsistency, incorrectness, incompleteness • Missing or extraneous information • Inappropriate organization • Inappropriate terminology • Nonconformance to standards
Specifications of Intermediate / End Products	• Untraceable requirements into original problem definition • Lack of understanding the problem • Inappropriate / inadequate degree of fidelity • Inconsistent / infeasible requirements • Inappropriate / inadequate environment • Immeasurable qualification • Missing functions and features
Transformation Mechanism	• Unclear equations and algorithms • Inappropriate equations and algorithms • Too many assumptions and limitations • Missing elements, and modal-able pieces and interactions • Missing links between modules
Input / Output	• Unavailable input • Inadequate input / output definition • Invalid input • Invalid default input • Output inadequacy to the degree of fidelity • Difficulty in validating the output • Excessive boundaries
User Interface	• Non user-friendly interfaces • Missing features • Extraneous features

The next step is "identifying the questions to ask". The purpose of identifying question is to clarify the uncut risk areas determined at the previous step. Here, the product, its vulnerable part, and undesirable weakness in that product are to be specified. The samples for questions are shown in Table-4.

Table-4. Examples for Questions to Ask.

Vulnerable Part	Vulnerability	Product	Question
Documentation	Nonconformance to standards	Problem Definition Document	Does the document format comply with the applicable standards?
Specifications	Untraceable requirements into original problem definition	M&S Requirements	Are the requirements traceable to the problem definition?
Transformation Mechanism	Too many assumptions and limitations	Conceptual Model - assumptions associated with the solution approach	Are the assumptions reasonable and in scope of the problem definition?
Input / Output	Invalid default input	Model Design	Are the initial default inputs to the model adequate?
Input / Output	Output inadequacy to the degree of fidelity	Model Code	Does the model yield outputs as adequate to fidelity requirements?
User interface	Non user-friendly interfaces	Test & integration	Are the user interfaces easy to understand the features of the model?

Now, the acquirer is to select the appropriate verification and validation techniques based on the risk areas and questions formed. For the linkage between the questions and the verification and validation techniques to be selected, I used an approach that I tried to match the vulnerable parts of a product with the accuracy indicators of a product, as shownin Table-5. Based on the definitions of the accuracy indicators,

- Documentation, specification, and mechanism are related with the structural accuracy,
- Input and output are related with the transformational accuracy,
- User interface is related with the interface accuracy.

Table-5. The Relation Between Accuracy Indicators and Vulnerable Parts of a Product.

	Accuracy Indicators		
Vulnerable Parts of Product	Transformational Accuracy	Interface Accuracy	Structural Accuracy
Documentation			X
Specifications of products			X
Transformation mechanism			X
Input / Output	X		
User Interface		X	

Using those relationships, a matrix (Table-6) for the verification and validation techniques and vulnerable parts of the product can be built. The acquirer is to select the verification and validation techniques using this type of table, and based on the risk areas, and questions formed.

Table-6. Cross-reference Matrix for V&V Techniques and the Vulnerable Parts of a Product.

	Vulnerable Parts of Product				
V&V Techniques	Docs	Specs	Trns.Mech.	I/O	U-Interface
Face Validation	X	X	X	X	X
Inspection	X	X	X	X	X
Review	X	X	X	X	X
Walkthrough	X	X	X	X	X
User Interface Analysis					X
Traceability Assessment	X	X	X		
Sensitivity Analysis				X	
Comparison Testing				X	
Functional Testing				X	

The selected verification and validation techniques denote the tasks to be performed for verification and validation activity. The Table-7 shows the tasks for a scenario, where

- The vulnerable part is documentation,
- The vulnerability is non-conformance to standards,
- The product is the "Problem Definition Document",
- The question is "Does the document format comply with the government documentation standard?"
- The selected verification and validation technique is "Review".

Table-7. Sample V&V Tasks.

No.	**Tasks to Answer Question**
1	Decide on the criticality of the document.
2	Tailor the standard GDS-002 for the subjected document.
3	Prepare a checklist according to the tailored standard GDS-002.
4	Disseminate the document to be reviewed and the checklist to the reviewers.
5	Let the reviewers examine the document in the light of the checklist.
6	Conduct a meeting with the participation of the reviewers and evaluate the subjected document.
7	Document the results of the evaluation of the subjected document.

The last step in "Planning Verification and Validation" is to prepare the verification and validation implementation plan. From the literature survey [2,9,12,13,14,15,16], the minimum content for a verification and validation plan is given in Table-8.

Table-8. Minimum Content for a V&V Implementation Plan.

No.	Content	Description
1	V&V Responsibilities	• V&V organization, and personnel assignments.
2	Information Sources	• All documentation related to the model / simulation to be subjected. • Subject matter experts, • Real world data for use as comparative data, • Summary of the results of any previous V&V efforts.
3	Methodology, Techniques, and Tools	• The planned V&V techniques / methods, • The limitations that may hinder the analysis, • The reason for why they were chosen, • The depth of the planned tests, • Any decomposition strategy, • The intended depth of the investigation effort.
4	Tasks and Milestones	• Tasks, • Resources requirements, • Schedule for completion of each task, • Any dependencies among tasks.

The verification and validation plan is implemented in the "Performing Verification and Validation" step. I propose that the activities to be performed by a team. The defects and issues found in the product verified / validated are to be graded according to their severity, such that in Table-9.

Table-9. Severity Levels for Defects and Issues.

Severity Level	Description
1	The defect / issue found does not affect the intermediate product of the next phase, and the successful completion of the development (e.g. inappropriate terminology, inappropriate documentation organization, unreadable document, extraneous information, etc.).
2	The defect / issue found may affect the intermediate product of the next phase, if not corrected / resolved (e.g. unclear equations and algorithms, immeasurable qualification etc.)
3	The defect / issue found changes the development goal (end product), if not corrected / resolved (e.g. unavailable input, missing functions and features, lack of understanding problem, etc.)

The last one in the three-step process of the proposed methodology is "Reporting Verification and Validation". The report is to have the minimum content [2,9,12,13,14,16] as shown in Table-10.

Table-10. The Minimum Content for the V&V Report Document.

No.	Content	Description
1	Executive Summary of V&V Results	• Critical issues, trends, and / or sensitivities of the model / simulation, • An objective picture of the strengths and weaknesses in terms of the intended use, • A specific statement regarding the confidence and credibility associated with the model / simulation in the context of its intended application.
2	Task Results	• The tasks performed during V&V of the product, • The result of the tasks including the defects and issues to be corrected / resolved.
3	Final Assessment	• Statements about the evaluation of the product, whether it is acceptable or not, why.

Case Study

In order to observe that the proposed methodology is applicable by the acquirer, and is adequate to the needs of the acquirer, I designed a case study.

A real project that is currently under development in the Modeling and Simulation Research and Application Center in the Middle East Technical University, is selected. In this project the acquirer is the government. The acquirer's project management office consists of four personnel who have mostly operations research background, and lack knowledge on the verification and validation activities. The project developer

group is the distinguished academic researchers from the university. The final product is being developed based on sequential intermediate products. The acquirer is to assess the acceptability of the intermediate products, and does not have any pre-determined methodology to apply. The intermediate products to be verified and validated are "Problem Definition Document" prepared by the Project Management Office, two Project Progress Reports prepared by the Project Development Group.

I assessed the applicability of the proposed methodology based on the three indicators (Table-11): completion time, request for modification on the steps determined in the proposed methodology, and the self adequacy of the verification and validation team in terms of support I provided to them.

Table-11. The Applicability Assessment of the Proposed Methodology.

	Time	**Modification**	**Support**
Problem Definition Document	• 8 hours • 4 workdays	• No modification to the steps proposed • Completely Implemented	• Methodology • V&V techniques • Checklist • Participation in reviews
Project Progress Report-1	• 24 hours • 7 workdays • Completed in time limits of the contract	• No modification to the steps proposed • Additional activity in Risk Determination	• V&V techniques • Checklist, traceability matrices
Project Progress Report-2	• 12 hours • 4 workdays • Completed in time limits of the contract	• No modification to the steps proposed • Additional activity in risk determination	• No participation in activities

The time data is based on the recorded time for the group activities. It does not include the time spent during individual activities of the team members. The verification and validation team members expressed their difficulties in finding enough time during work hours, and told that they spent extra time beyond the work hours. But the team members did not record those extra times. However, the verification and validation activities were completed in reasonable time duration, compared to the time limits given in the contract document of the project. The time limit was 10 workdays.

During verification and validation activities, the verification and validation team did not request any modification on the steps to be followed. The methodology was completely implemented.

The verification and validation activities performed by the team were completed in a reasonable time period with some extra effort.

The verification and validation team straightforwardly implemented the proposed methodology.

In each iteration of the verification and validation activity, the team got familiar with the terminology, methodology and the verification and validation techniques they used.

I assessed the adequacy of the proposed methodology based on the two indicators (Table-12): the number and severity levels of the defects and issues found, and the reaction of the development group to the findings.

Table-12. The Adequacy Assessment of the Proposed Methodology.

	The Number of Defects and Issues			The Reaction of the Developer Group
	Severity Level-1	Severity Level-2	Severity Level-3	
Problem Definition Document	10	8	2	N/A
Project Progress Report-1	15	9	0	• Agree with the findings
Project Progress Report-2	2	3	1	• Agree with the findings • Avoid making similar errors

The level 1 and 2 defects and issues do not change the nature of the final product, but the level 3 defects and issues are important. Finding 3 defects / issues with level 3 in early phases of the development must have enabled the later phases to be more error free.

The verification and validation reports were delivered to the development group. The group did not react to the findings with a resistance. They accepted those findings and corrected or maintained those reported defects and issues. Besides, they tried to avoid making similar mistakes in new reports.

Conclusions and Future Works

The case study results show that

- The proposed methodology can be applied completely,
- The acquirer can determine the activities for each step based on his/her own needs,
- The application time duration is reasonable,
- The acquirer can implement the verification and validation activities with short briefings on selected verification and validation techniques.

The focus of the proposed methodology and the case study is the early phases of the development. The application of the proposed methodology can be extended to the later phases of the development, which are model implementation/ coding, and test and integration. In order to improve the proposed methodology, we need metric data from at least two controlled implementations on two complete M&S projects.

A repository can be created with the results of those implementations, and can be shared among the practitioners.

When the repository got mature enough, an expert system can be developed based on this repository.

The effects of the developer's verification and validation activities on the outcome of the proposed methodology can be experimented too, since the developer's verification and validation activities were neglected in the case study.

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Challenges for Distributed Exercise Management: The SmartFED Approach

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Keywords: Exercise Management, Tools, HLA, FEDEP, Real-Time.

SUMMARY: *Distributed simulation requires a novel approach to exercise management and Verification, Validation and Accreditation (VV&A). With the introduction of (geographically) distributed simulations, exercise management consists of managing a multitude of simulators in a common scenario. This imposes new challenges with respect to managing the distributed responsibilities of the simulation. As with exercise management, distributed simulations impose new challenges on VV&A with respect to distributed responsibilities. NLR's exercise management tool SmartFED (Scenario Manager for Real-Time Federation Directing) is designed to meet these new challenges. This paper provides insight into SmartFED's concepts and practical experiences in the field of distributed real-time (training) simulations.*

Introduction

There is a growing interest in geographically distributed training/exercising using distributed simulation. Recently, applications have been published in the military [1], space [2] and civil aerospace [3] domain. Among the reported advantages are the (new) possibility to perform team training, the possibility to include real entities in the simulation, and cost reduction by saving on travel and subsistence.

Advances in research and technology create more and more new opportunities to make cost-effective use of distributed simulations. Standardisation efforts have resulted in novel intercommunication architectures and standardised processes for distributed simulation development. To take full benefit of distributed simulation in defence application areas like training, rehearsal, planning, acquisition and technology development, there are still challenges to be conquered.

Key challenges for distributed simulations include exercise management and verification, validation and accreditation. Distributed simulation requires a novel approach to exercise management. Traditionally, exercise management of single-site simulations consists of managing a single simulator. With the introduction of (geographically) distributed simulations, exercise management consists of managing a multitude of simulators. Also a novel approach is required for verification, validation and accreditation of distributed simulations. In practise, legacy simulators are adapted to be employed in a distributed simulation with other legacy and newly developed simulators. Implementation of requirements is, like the simulators, distributed, which is a challenge for verification, validation and accreditation.

To cope with these challenges, the National Aerospace Laboratory NLR has developed an High Level Architecture (HLA) based software tool-suite, Scenario MAnager for Real-Time FEderation Directing (SmartFED; see also [4], [5]). HLA was initiated by the Defense Modeling and Simulation Office (DMSO). SmartFED is a facility (i.e. tool-suite) to couple various autonomous, geographically

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dispersed real-time (legacy) simulators into one distributed real-time simulation. In HLA parlance, such simulators are called federates that collaborate in a federation to achieve the distributed simulation. The distributed responsibilities of the federation are managed by SmartFED, whereas each federate remains responsible for its own internal affairs. The same tools that are used for controlled distributed exercise management and monitoring are also used to facilitate structured, controlled and repeatable verification, validation and accreditation. As such, SmartFED supports several aspects of the HLA Federation Development and Execution Process (FEDEP) Model.

SmartFED has been successfully used as an indispensable core element in several civil and military programmes. The paper provides detailed insight into the concepts of SmartFED, the practical experiences with SmartFED in the field of distributed real-time (training) simulations, also in defence, and how these concepts and experiences translate back to resolving challenges in modelling and distributed simulations.

The remainder of this paper is organized as follows. In the section ‘Distributed Real-Time Simulation’ distributed real-time simulation and the use of SmartFED in a typical aerospace application is described briefly. The section ‘Exercise Management: The Concepts’ presents the concepts of exercise management. SmartFED-supported distributed exercise management is detailed in the section ‘SmartFED Supported Distributed Exercise Management’. At present the SmartFED tool-suite consists of three distinct tools: a federation manager tool, a federation monitor tool and a scenario definition and execution manager tool. These three tools are described in more detail in the sections ‘Federation Manager’, ‘The Federation Monitor’ and ‘The Scenario Definition and Execution Manager’. The section ‘VV&A Support’ describes how SmartFED supports Verification, Validation and Accreditation of distributed simulations. The section ‘FEDEP Support’ elaborates on how SmartFED supports the FEDEP process. Finally, concluding remarks and items for future work are presented in the section ‘Concluding Remarks and Future Work’.

Distributed Real-Time Simulation

An artist’s impression of a SmartFED application pursued within NLR is given in Figure 1. The application deals with a total solution concept in the area of Air-Traffic Management (ATM)-gate-to-gate. Individual players, e.g. aircraft, airport, and ATM, are supported by dedicated facilities at NLR.

To aid simulated entities to interact in the virtual world, in a similar fashion as the real players, proper exercise management is required. For this, SmartFED has been developed.

To fully exploit the advantages of distributed simulation exercises three fundamental cornerstones can be identified:

1) A standardized intercommunication mechanism. This has been addressed, first with DIS (Distributed Interactive Simulation) from which evolved HLA (High Level Architecture) [6]. At present SmartFED is based on HLA. In HLA parlance, simulation entities are called federates that collaborate in a federation to achieve the distributed simulation.
2) A standardized process for federation development and execution. Besides intercommunication standardization, HLA also brought the FEDEP process [7] to address this aspect.
3) Exercise management. There is no standardization yet on this aspect, though HLA offers some useful handholds. Distributed simulation requires a novel approach to exercise management. Traditionally, exercise management of single-site simulations consists of managing a single simulator. With the introduction of (geographically) distributed simulations, exercise management consists of managing a multitude of simulators. This imposes new challenges with respect to managing the distributed responsibilities of the simulation.

Figure 1: SmartFED in an ATM gate-to-gate federation concept.

SmartFED has been successfully used as an indispensable core element in several programs since its inception in 1996. A more detailed insight into the concepts of SmartFED and the practical experiences with SmartFED in the field of distributed real-time (training) simulations is given in the remainder of this paper. First however the concepts of exercise management will be discussed.

Exercise Management: The Concepts

Exercise management, for both single-site and distributed simulations, can be split into four distinct functionalities grouped into two major responsibilities:

1) Simulation execution state management
   a) Monitor the execution state
   b) Control the execution state
2) Simulation scenario management
   a) Monitor the simulation objects
   b) Control the simulation objects

Whilst both single-site and distributed simulation exercise management comprise the same functionalities, exercise management for distributed simulations is decisively more complex than for single-site simulations.

Whereas a single-site simulation usually has a well-defined execution state, the concept of execution state of a distributed simulation can often not be defined uniquely. Depending on the simulation exercise at hand the concept of execution state can be very strictly or more loosely defined. For example, when deploying legacy single-site simulators in a distributed simulation exercise, a very strict definition of state could very well be unfeasible, so that the application of a more loosely defined execution state is necessary.

As is the case for state of execution, also scenario management of distributed simulations is more complex when compared to single-site simulations. Simulation objects in a distributed simulation can be controlled by two different concepts:

1) Request driven concept, where the scenario manager requests state changes of simulation objects from their controlling simulator.
2) Active control concept, where responsibility of simulation object attributes is transferred to the scenario manager. The scenario manager then has unrestricted direct control over those attributes.

Of course a mixture of these concepts is necessary, especially since federates may need special safety-measures, e.g. the safety of a pilot in a full motion flight simulator. The choice of which concept is used thus depends on the federates involved in the federation. Especially legacy simulators impose limitations on the amount of external influence that can be inflicted on the simulation objects under their control.

SmartFED Supported Distributed Exercise Management

A typical distributed exercise management situation utilizing SmartFED is depicted in Figure 2. In this case two human entities are identified, which together collaborate to perform exercise management. Whereas the supervisor controls the progress of the simulation execution, the trainer controls the content of the simulation execution.

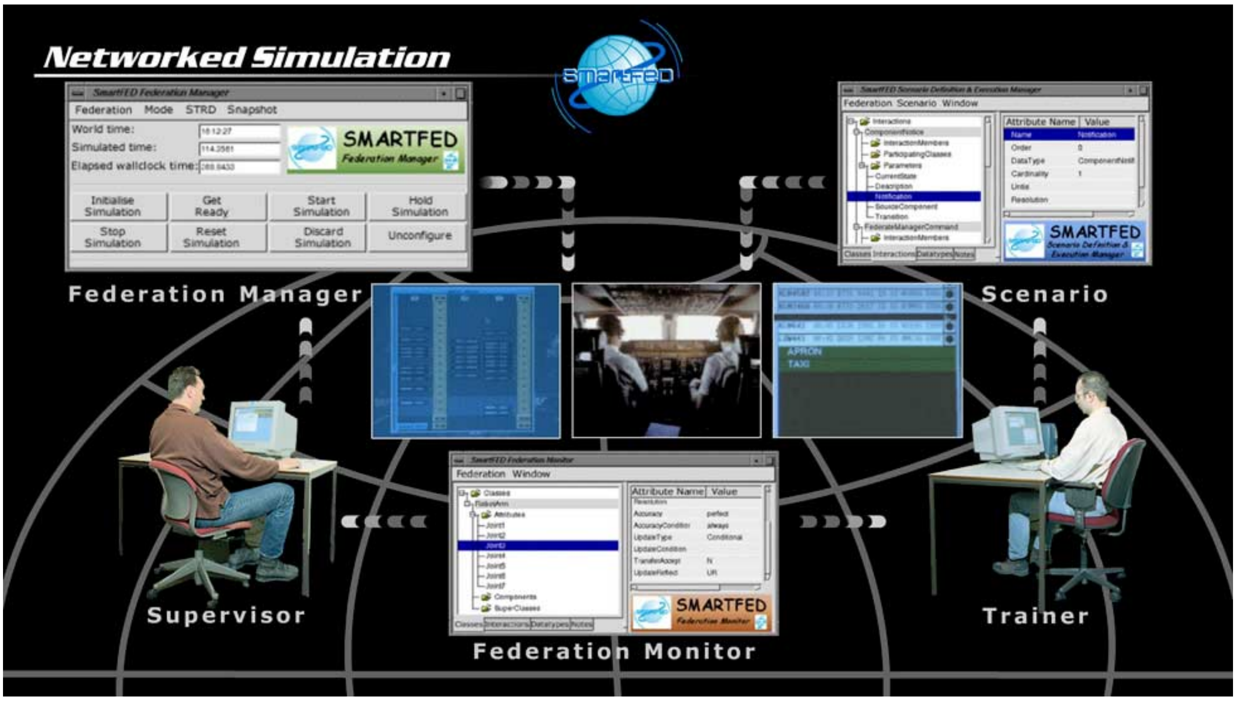

Figure 2: Typical (simplified) distributed exercise management situation involving aerospace federates.

SmartFED is a generic reusable tool-suite that provides support to the human exercise manager(s) controlling a real-time distributed simulation execution. At present the tool-suite encompasses three tools:

1) Federation Manager (FedMan): this tool implements support for simulation execution state management. It encompasses both monitor as well as control functionalities.
2) Federation Monitor (FedMon): this tool implements support to monitor simulation objects. It is remarked that more than one instantiation of FedMon is possible in a federation.
3) Scenario Definition and Execution Manager (SDEMan): this tool implements support to control simulation objects by means of both repeatable and interactive scenarios.

Some of the important properties of SmartFED are:

- HLA compliancy. SmartFED is a tool-suite where each of the tools operates as an HLA compliant federate. Although SmartFED has been designed to be fully HLA compliant, it has also been successfully ported to use a custom intercommunication protocol based on CORBA.
- Simulation scenario management support. Within SmartFED this support has been separated into two tools (i.e. FedMon and SDEMan) to facilitate multi-site monitoring, whilst preventing conflicts due to multiple controlling entities.
- Control concept. Currently SmartFED supports the request driven concept. A future version of SmartFED will also support the active control concept.
- FEDEP support. SmartFED supports the Integrate and Test Federation and the Execute Federation and Prepare Results steps (5 and 6 respectively) of the FEDEP model. The FEDEP support of SmartFED will be further discussed in the section 'FEDEP Support'.

Federation Manager

The SmartFED Federation Manager (FedMan) provides central control over the distributed real-time simulation. The human supervisor (see also Figure 2) operates the Federation Manager from any one of the participating sites.

FedMan has the ability to monitor the execution state of each of the participating federates. This enables the supervisor to take informed decisions on his control strategy and to monitor the effects of his actions. FedMan supports control of federation execution state by means of a general state transition diagram (STD), which is depicted in Figure 3.

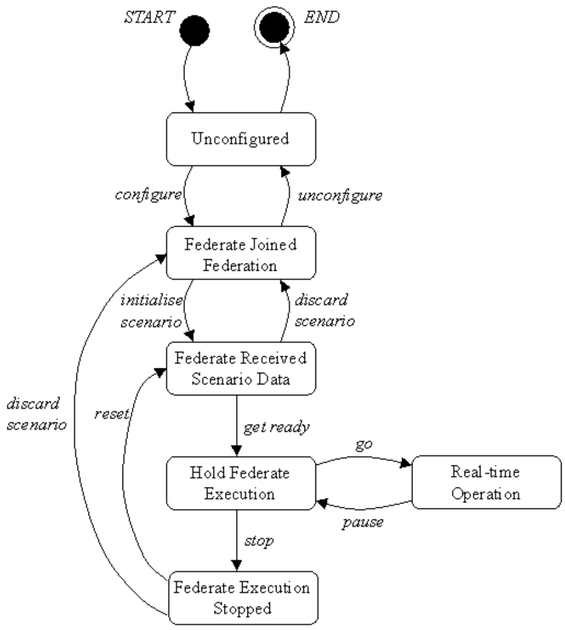

Figure 3: Federation state-transition diagram.

It is important to note that SmartFED does not impose any restrictions on a federate’s internal STD. Federates may well possess an internal STD that differs from the one depicted in Figure 3. The main issue is that from an exercise management point of view, a federate complies with the depicted STD. FedMan sends state-transition commands to all federates. If applicable with regard to the selected control mode, federates reply with success or failure notifications.

During federation development it may appear that federates cannot comply with a federation STD since federates may have their own internal STD. Especially legacy simulators are made HLA compliant by building an HLA data gateway, which does not support external influence on flow of control. To deal with federations that utilize these kind of federates; FedMan supports two modes of control.

A strict control mode is available that enforces all federates to transfer into a requested state before the supervisor can forward execution to a next state. The second mode of control is a free-running mode that doesn't enforce federation wide state synchronization. An example of a federation executing in free-running mode is depicted in Figure 4; note that different states are indicated for participating federates. The mode of control is selected at start-up of a federation and cannot be changed during federation execution.

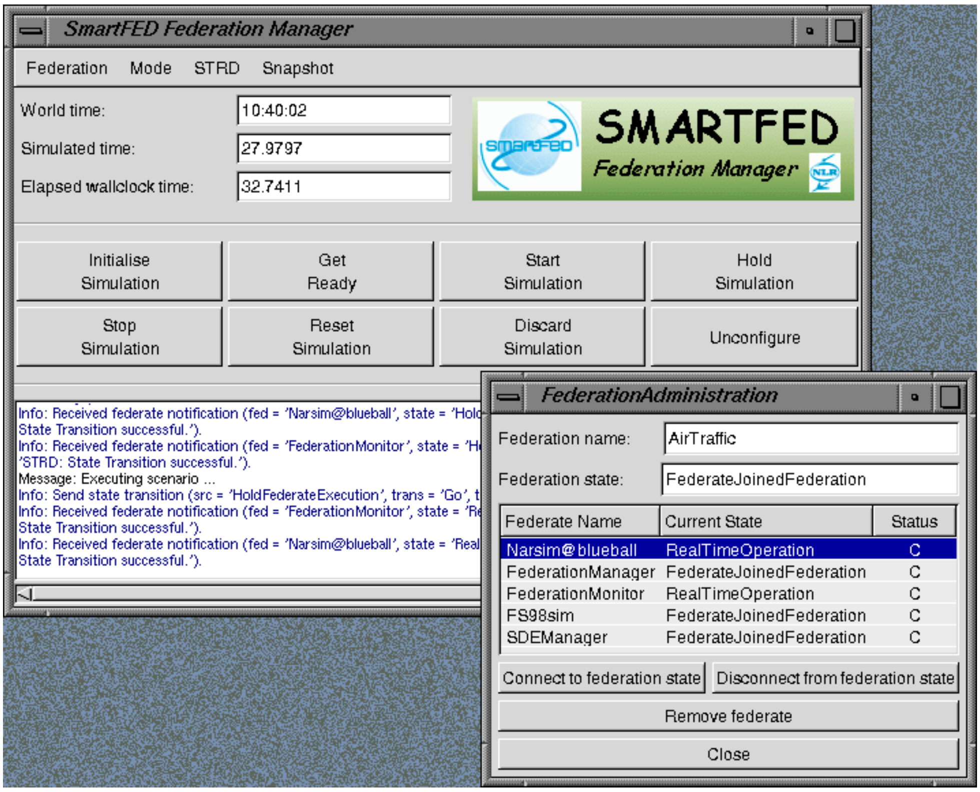

Figure 4: SmartFED Federation Manager.

For monitoring purposes FedMan provides a dedicated message window to notify the supervisor of warnings or errors that occur during the federation execution, for instance when a federate does not comply with a state transition request.

The Federation Manager supports the initiation of snapshots by sending a snapshot requests to the participating federates. A snapshot usually contains a dump of the entire internal state of a federate. Of course this is only possible as far as a federate supports snapshots. In order to preserve the real-time nature of the simulation, snapshots can be generated only when a federate is in the 'Hold Federate Execution' state.

The Federation Monitor

The SmartFED Federation Monitor (FedMon) provides information about simulation objects within an entire federation. The supervisor and the trainer (roles identified in Figure 2) both take advantage of the FedMon monitoring facilities, though they are by no means the only possible beneficiaries of the use of FedMon. FedMon can be instantiated as many times and on any location as is deemed beneficial. An example screenshot of several of these monitoring facilities and their display formats is depicted in Figure 5.

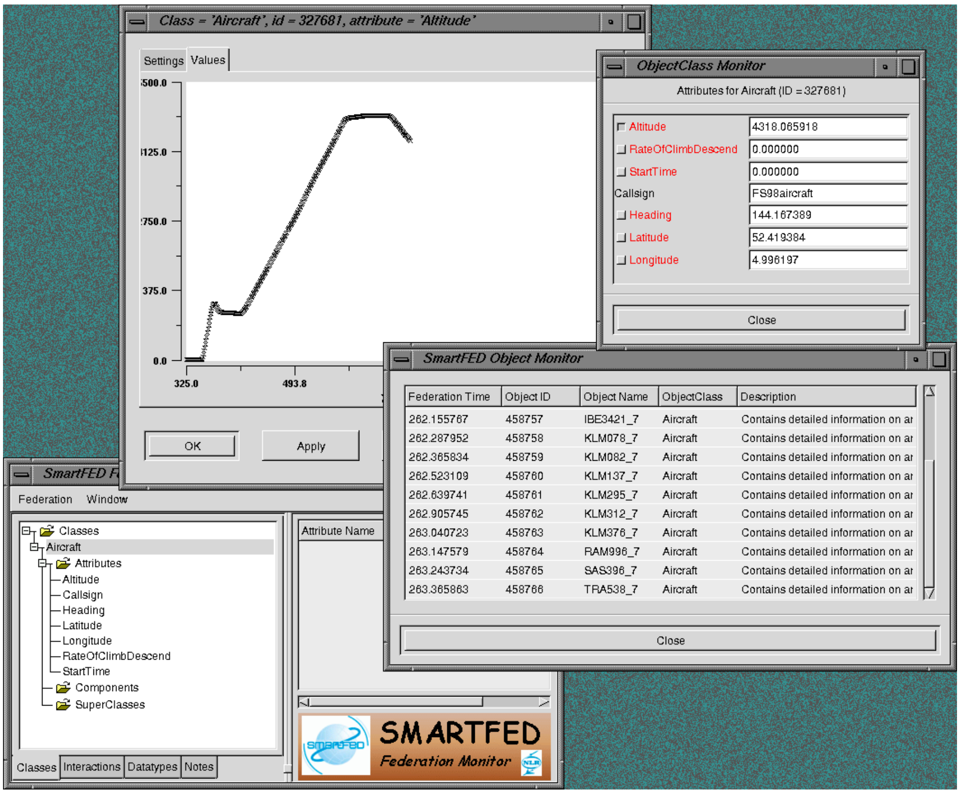

Figure 5: SmartFED Federation Monitor.

In HLA parlance, a simulation object can be either an instantiation of an object class or an instantiation of an interaction class. The difference is principally that an object has a significant lifetime, whilst an interaction takes place at a moment in time after which the interaction seizes to exist. HLA provides a standardized means to describe object and interaction classes that exist within a federation. For each federate a Simulation Object Model (SOM) must be defined. The SOM defines object and interaction classes that can be published or subscribed by that federate. Federation wide, a Federation Object Model (FOM) must be defined. The FOM describes object and interaction classes from a federation point of view.

FedMon uses the FOM to structure access to all information available within the federation. A graphical representation of the FOM enables users to subscribe to information of their interest.

FedMon provides both textual as well as graphical facilities to represent information about the federation and its simulation objects. Information monitoring can be categorized in three abstraction levels:

1) Simulation object/interaction class level. An overview can be displayed of all simulation objects in the federation of an indicated class.
2) Simulation object/interaction level. This level is supported by:
   a) a so-called Planview oversight. This monitoring facility is aimed at providing a 2D-overview of simulation objects that possess a simulated geographic location on earth, in the air or in space.
   b) an overview of all attribute/parameter values. The attributes/parameters are represented by the textual values.
3) Simulation object attribute/interaction parameter level. The user has the capability to configure views for specific attributes. For example, it is possible to view an attribute change over time.

The Scenario Definition and Execution Manager

The Scenario Definition and Execution Manager obviously has two main tasks: scenario definition and scenario execution. The Scenario Definition component enables the user (e.g. the trainer in Figure 2) to specify a scenario prior to simulation execution. A scenario consists of the following parts; an example is depicted in Figure 6:

- Federation composition: defines the federation name and defines which federates in the federation participate in the specific scenario;
- Initial condition definition for each federate: the initial values of the federates data attributes (e.g. an aircraft position, speed);
- Stimuli definition during scenario execution: which events must occur at what time during the scenario.

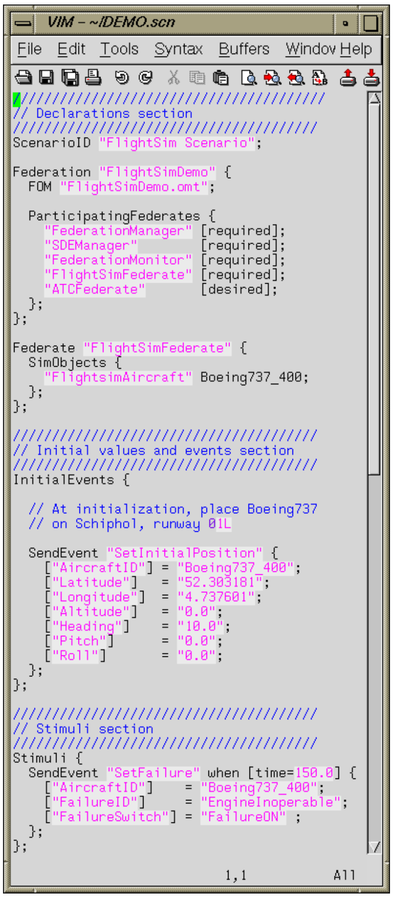

Figure 6: SmartFED Scenario file example.

SDEMan reads the predefined scenario file and sends all initial events to the federation when the Federation Manager generates the ‘initialise scenario’ command (see Figure 4). During the ‘Real-time Operation’ state (see Figure 3) the Scenario Execution component will send events to the federation at the times specified in the scenario.

The scenario definition capability gives exercise management the possibility to (re-)play predefined training exercises. However, during exercise execution it may often be necessary to provide the trainee(s) with ad-hoc generated events. Examples are the generation of failures or the generation of additional (friend and foe) objects.

The SmartFED scenario execution manager supports this capability by allowing the exercise manager to generate in principle all events that are defined in the FOM. In this way the scenario execution manager is more or less “symmetric” to the federation monitor: the monitor allows subscribe/unsubscribe actions

with respect to the FOM classes and events, while the scenario execution manager allows publish actions.

VV&A Support

The increase of interest in (distributed) simulation has also lead to an increase in Verification, Validation and Accreditation (VV&A) needs. Today, important decisions are often made that rely heavily on simulation results. "Bugs" in simulation could therefore have considerable economic or even safety effects. VV&A for distributed simulation is described in detail in [9].

There is a remarkable similarity between scenario management and VV&A. In practice, VV&A will result in the definition and execution of numerous tests. In general, test definition consists of defining test cases and test procedures. Test cases consist of sets of input stimuli and expected output responses. The test procedures are the actions to be performed to execute the test cases. During test execution, the test cases are executed and the actual results are compared with the expected ones, giving pass/fail results. From the discussion on the SmartFED SDEMan capabilities it is clear that the scenario mechanism can be used to define the input part of the test cases. The actual test results can be obtained by monitoring the data and events using SDEmon.

Although not designed to perform formal VV&A, it is observed in practice that SmartFED is often used as a useful federate and federation testing tool. Usually, three levels of testing are distinguished for a federation (see also [7]):

- Federate testing: to verify compliance of each federate with its allocated requirements (as documented in for instance the FOM).
- Integration testing: to verify a basic level of interoperability between the federates comprising a federation.
- Federation testing: the ability of the federation to interoperate to the degree necessary to achieve federation objectives is verified.

Federations can be tested using SmartFED on all levels. At the moment it being investigated whether the SmartFED capabilities should be enhanced to incorporate more testing capabilities. An example of such a capability is the possibility to automatically compare actual obtained federate/federation responses with expected ones. The scenario format as described in the section ‘The Scenario Definition and Execution Manager’ could be easily expanded to include this capability. However, in practice this would require for test case definition an exact description of the expected outputs, and, as illustrated in e.g. [10], the verification and validation of simulators is usually performed with respect to reality, which is most difficult to specify. Moreover, the behavior of simulations often results into graphic or mechanical effects, and not by (HLA based) object data or events that could be monitored.

FEDEP Support

The HLA Federation Execution and Execution Process (FEDEP) model [7] describes a high-level framework for the development and execution of HLA federations. The intent of the FEDEP model is to specify a set of guidelines for federation development and execution that federation developers can use to achieve the needs of their application.

The FEDEP process is depicted in Figure 7. SmartFED supports the Integrate and Test Federation (step 5), the Execute Federation and Prepare Results (step 6) and partially the Develop Federation steps (step 4) of the FEDEP model with the following capabilities:

- Federate testing is supported to validate the various federates with respect to the FOM. By performing this kind of (stand-alone) validation before the federates are integrated into the overall federation (usually by a “big bang” integration) faults can be detected and repaired at an early stage, thereby saving time and reducing costs.
- Federation integration testing is supported where the integrated federation is tested to “verify a basic level of interoperability”. Testing the state transition diagram of FedMan can easily test this basic level of interoperability.

- Validating the complete integrated federation against the FOM.
- Scenario instances (input to step 5) can be implemented by the scenario file mechanism of SDEMan as discussed in the section 'The Scenario Definition and Execution Manager'.
- SmartFED provides logging files to support after action reviews of federation execution.

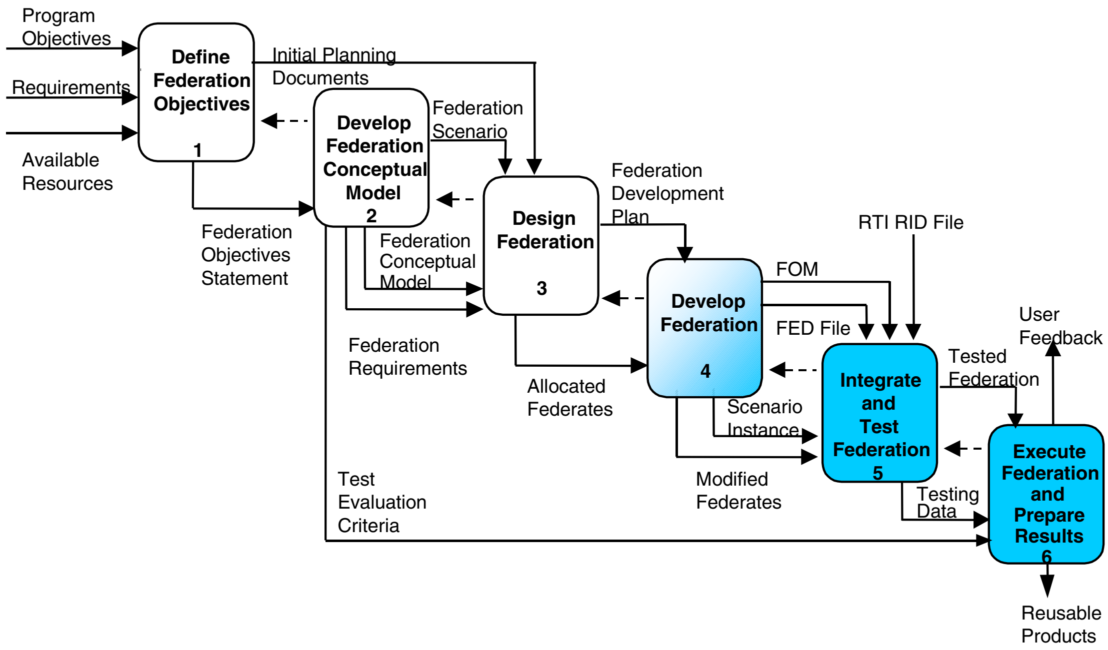

Figure 7: FEDEP's six-step model (from [7]).

Concluding Remarks and Future Work

The growing interest in utilization of distributed simulations has led to the development of a standardized intercommunication mechanism as well as a standardized process for federation development and execution. Exercise management has not been standardized yet. This has led to the development of the Scenario MAnager for Real-Time FEderation Directing (SmartFED) tool-suite, which provides tool support for distributed exercise management in real-time. Though SmartFED was primarily designed for distributed exercise management, it can also be used as a valuable tool for VV&A. The SmartFED tool-suite is successfully used in a number of aerospace projects.

SmartFED utilizes the standardized intercommunication mechanism HLA and supports the standardized FEDEP process. Several practical applications utilize SmartFED from which experiences are gathered and used for product improvement. The generic State Transition Diagram (STD) deployed by the FedMan tool will be enhanced by the support for a user-defined federation execution STD. The current generic STD will still be available as a default instantiation of such a user-defined STD.

A limiting factor in worldwide simulation through connecting simulation facilities using for instance HLA is often the available bandwidth. The SmartFED tool-suite will be extended with a so-called Federation Timing tool (FEDTim) that can be used to perform specific measurements on data flows between federates in a federation.

The use of an automated tool to validate a federate/federation (as discussed in Section 'VV&A Support') may raise questions about the quality of the tool. To anticipate this, SmartFED is in the process of being qualified as verification tool in the sense of [8]. In [8], software verification tools are described as tools that cannot introduce errors, but may fail to detect them (this in contrast to development tools, that can introduce errors). SmartFED tool qualification now consists of demonstrating that “the tool complies with its Tool Operational Requirements under normal operational conditions”. Basically, this means that SmartFED is undergoing a stringent verification process, with several test federations.

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Areas of Simulation Standards

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Executive Summary

This report is the result of an exploratory study for the identification of a NATO Technical Activity Program (TAP) on M&S standards and was performed in the context of the NATO Modelling and Simulation Group 13 (MSG-013).

The aim of this report is to define areas where standards for M&S are required, to compare the situation with the currently available standards, and to draw some appropriate conclusions.

In Chapter 1, we give a short introduction into this work.

In Chapter 2, we describe areas, where standards for M&S are required and why these standards are required, taking the virtual system lifecycle as a guiding principle.

In Chapter 3, an overview is given on already existing standards in the area of M&S, the extent they possibly could be used and their deficiencies.

In Chapter 4, we present some ideas how to adapt existing standards and will give general descriptions of standards which still have to be developed.

In Chapter 5, we discuss the feasibility of missing standards, especially organizational implications and costs-aspects.

1 Introduction

Currently, there are multiple efforts on national and international (e.g. NATO) levels for time- and cost-effective provision of optimized military capabilities using modelling and simulation (M&S) technologies (see e.g. the NATO M&S Master Plan [1] and national documents, e.g. for the US Army [2] or the German Forces [3]). Pre-requisite for this is the availability of a large number of M&S elements, e.g.

- models,
- simulations (either complete simulation systems or simulation components),
- data to establish the initial and boundary conditions for the application of models and simulations, and
- suitable tools for supporting the preparation, execution and evaluation of simulations.

In context with the technical and economical feasibility of the adaptation and/or development of these elements, covering the extended spectrum of involved systems over all phases of their life cycles and considering the specific needs of all military echelons, standardization plays a significant role.

Paper presented at the RTO NMSG Conference on "Future Modelling and Simulation Challenges", held in Breda, Netherlands, 12-14 November 2001, and published in RTO-MP-073.

2 Requirements for M&S standards

There are two key areas for standardization:

- communication, interaction and data exchange between people and/or systems,
- integration of components and systems into different systems,

both of course with the ultimate goal of saving costs and time.

The degree of standardization within a certain field of technical applications is an indicator for the matureness of this field: a new area will typically show no or just a few standards, whereas a well developed, mature area will be reigned by quite a lot of standards. Of course, this implies also that a thoroughly standardized area will not show such a high degree of dynamic development, compared to a new, just emerging area where standards still have to be found or even have to be defined.

But there remains the conclusion, that overall, as soon as a specific system (e.g. a tool, a piece of software, a simulation system or a simulation component) follows a certain set of standards, the probability for acceptance of this system will increase. On the other hand, standards will be accepted much more easily if their use is supported, e.g. by appropriate tools.

Experience shows that standards will be created and accepted best if there is a technical or economical need for them.

Public, non-proprietary standards usually have to be issued by an organization that is given the right to do so, e.g. SISO or IEEE. But in this report, we will consider emerging standards as well: so-called de-facto standards which have apparently the chance to become officially approved standards in the near future.

In this chapter, we will deduce the areas for M&S standards in a 4-step procedure:

1. Considering the complete life cycle of a system which may be required in context with the acquisition of a necessary military capability, we will identify those areas which can be supported by the employment of M&S technologies.
2. In a second step, we will identify superior goals which we intend to accomplish by the use of M&S in the process of acquiring a necessary military capability.
3. In a third step, we will identify the resulting requirements for the M&S elements.
4. Finally, in a forth step, we will work out candidate areas of standardization for M&S.

The context of acquisition of necessary military capabilities is selected here because it covers almost all aspects of the use of M&S, as is intended by Simulation Based Acquisition (SBA) procedures. Nevertheless, the other fields of use of M&S (defense planning, training, exercises, support to operations, research, and technology development) are covered implicitly as well.

2.1 Modelling and Simulation in the virtual system life cycle

As discussed e.g. in [4], M&S can be applied for each phase of a system live-cycle: requirements analysis, conception phase, design, development, building, testing (leading to operational systems), training and exercise, logistics and supply (leading to combat-ready systems), and further for employment planning, mission rehearsal, operational support and employment-analysis (finally leading to optimized systems fulfilling optimized requirements).

The basic idea is, to improve the effectiveness of providing a needed capability in terms of time, cost and quality by thoroughly using M&S instead of time- and cost-consuming real systems, wherever possible.

This leads to the vision of the *virtual system life-cycle*, allowing to replace the present “design, build, test, fix”-procedure by a “design, simulate, fix, build”-procedure.

The idea of using M&S within a system live-cycle is not new; e.g., simulations have been and are used within several steps of the life cycle. But the ultimate aim is the full simulation of the complete system life cycle, which can be easily iterated many times (e.g. during the early phases of a procurement project, i.e. during the requirements analysis and the conception and design phases) [5], [6].

In general, such a completely simulated life cycle will be composed of several simulation systems and other M&S elements. Therefore, in the next sections we will identify the requirements that must be fulfilled by simulation systems and other M&S elements to be used in this context.

2.2 Superior goals for M&S employment

There are three superior goals for the employment of M&S in the process of acquiring a necessary military capability:

1. minimization of acquisition costs,
2. minimization of acquisition time, and
3. maximization of acquisition quality.

To clarify the last goal, it makes sense to split this goal into three subitems:

a. minimization of risk (improvement of time and cost estimates, and improvement of project control),
b. optimization of system requirements, and
c. optimization of system behaviour and system use.

The resulting structure of these superior goals is shown schematically in the upper part of figure 1.

The goals are independent from the application domain. However, they form the basis for the derivation of requirements for simulation systems and other M&S elements.

2.3 Requirements for M&S elements

The above superior goals lead to the following general requirements for simulations and other M&S elements (see figure 1):

1. From the superior goals "Minimization of acquisition costs" and "Minimization of acquisition time", follows immediately the requirement "Re-usability", e.g. of simulation systems: since simulation systems will play an ever increasing role in the acquisition processes, re-use of simulation systems as compared to repeated new developments is a significant issue regarding time and costs savings. (Re-usability of simulation systems can have different meanings: it may mean the re-use of a simulation system in another step of the life cycle for the same project, or the re-use of a simulation system in the life cycle of another project.) But re-use may be applicable to all other M&S elements as well (e.g. databases or tools) [7].

2. Closely connected to the first point (i.e. saving costs by re-use of M&S elements), is the possibility of connecting simulation systems, components and tools together, aiming at a new, larger simulation system. Thus the requirement "Interoperability" can be deduced from the superior goal "Minimization of acquisition costs". Also the interoperability between simulation systems and other systems is of increasing importance, e.g. the connection to C3I-systems for the efficient use of simulation systems in CAXes or as DST.

   These two requirements, re-usability and interoperability, are well known and worked out e.g. in the NATO MSMP [1]. In addition, we find two further requirements:

3. The requirement "Usability" follows again directly from the superior goals "Minimization of acquisition costs" and "Minimization of acquisition time". By usability we mean basic properties like:
   - user friendliness (appropriate user interface, easy-to-install, etc.),
   - availability (support of different platforms, absence of proprietary restrictions, etc.), and
   - sufficient support (documentation, specific training, hot-line, tools for configuration management or the retrieval of project information, etc.).

4. The requirement “Credibility ” follows directly from the superior goal “Maximization of acquisition quality”, and the corresponding subgoals. But this requirement can also be deduced from the other requirements “Interoperability” and “Re-usability”: only systems or databases, which are supposed to be correct and credible, will be re-used easily.

In principle, each of the four areas of requirements for simulations and other M&S elements follows from all superior goals for M&S employment, but the connections between goals and requirements are of different importance. The key-question here is: how important is a specific requirement for simulations and other M&S elements for reaching the different superior goals for M&S employment? An exact answer could only be given by a thorough analysis of a significant number of completed acquisition projects. Instead, we will try a rough estimate.

In table 1a, we give a semi-quantitative estimation of the importance which a specific requirement has for reaching a superior goal (with a scale from 0 to 5, 0: no significant importance, 5: very high importance).

In table 1b, the importance numbers from table 1a are weighted by the appropriate sums per row from table 1a. These normalized importance numbers will be of use in the next section.

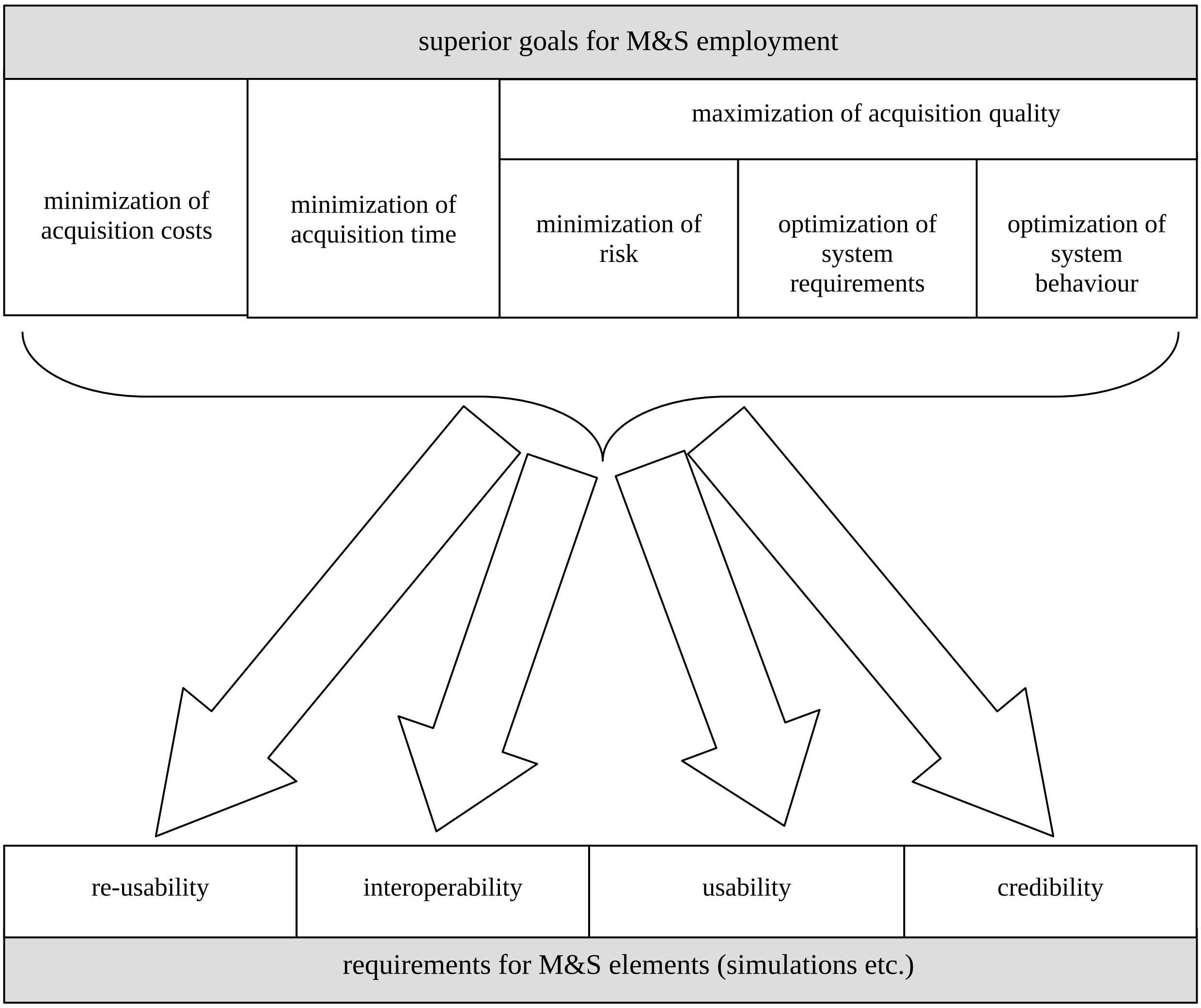

Fig. 1 Deduction of requirements for simulations and other M&S elements from the superior goals for M&S employment

superior goals	requirements for M&S elements				sums
	re-usability	interoperability	usability	credibility	
minimization of acquisition cost	5	5	5	3	18
minimization of acquisition time	5	4	3	3	15
minimization of acquisition risk	2	2	2	5	11
optimization of requirements	0	1	3	3	7
optimization of system behaviour	0	1	2	3	6

Table 1a: Importance of the requirements for simulations and other M&S elements for reaching the superior goals for M&S employment (0: no significant importance, 5: very high importance).

superior goals	requirements for M&S elements			
	re-usability	interoperability	usability	credibility
minimization of acquisition cost	0.28	0.28	0.28	0.17
minimization of acquisition time	0.33	0.27	0.20	0.20
minimization of acquisition risk	0.18	0.18	0.18	0.45
optimization of requirements	0.00	0.14	0.43	0.43
optimization of system behaviour	0.00	0.17	0.33	0.50

Table 1b: Normalized importance of the requirements for simulations and other M&S elements for reaching the superior goals for simulation employment (the importance numbers from table 1a are normalized per row).

2.4 Areas of standardization for M&S

From the requirements for simulations and other M&S elements, several areas of standardization for M&S can be deduced (see figure 2).

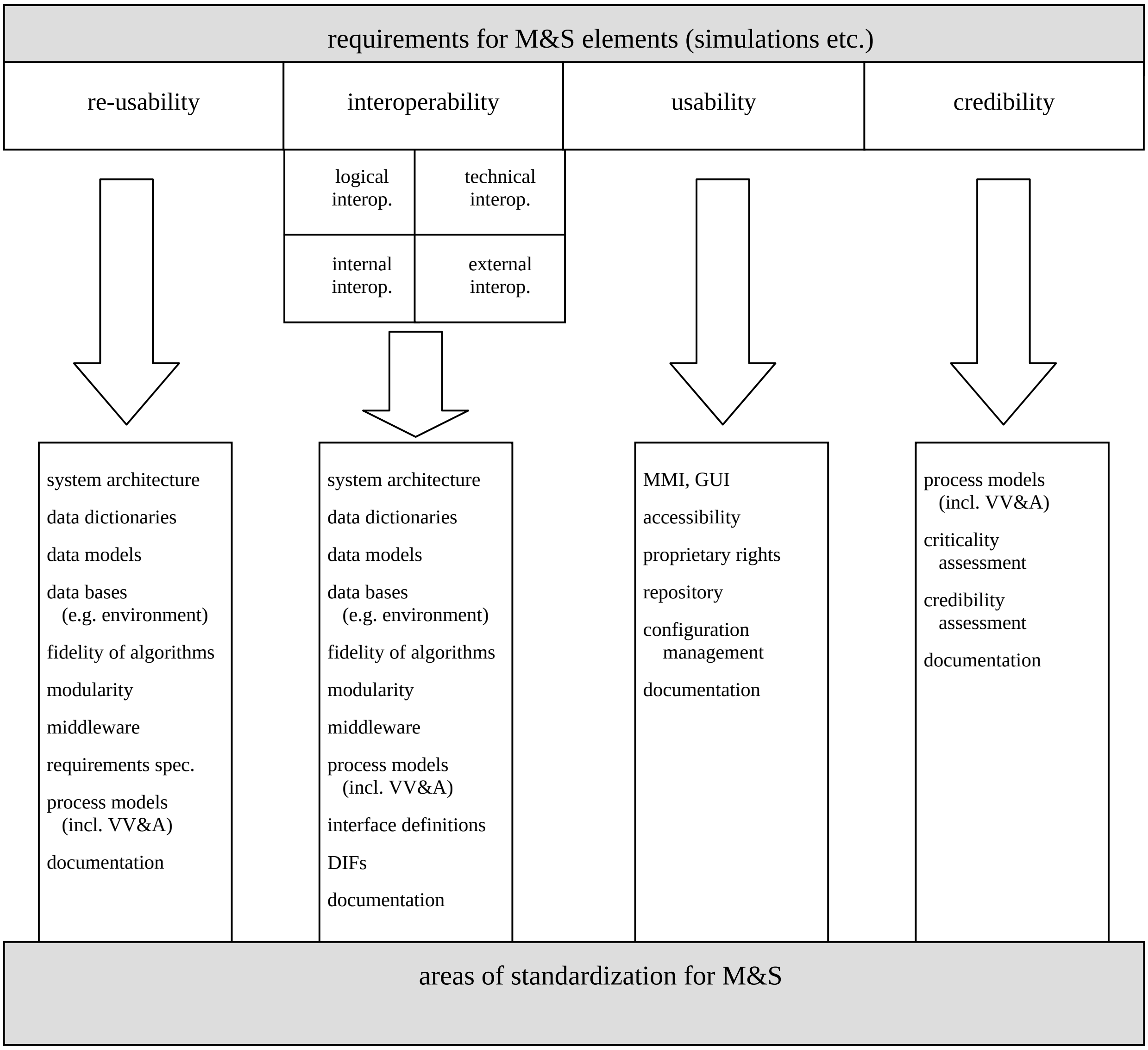

Fig. 2 Deduction of areas of standardization for M&S from requirements for M&S elements

For clarification, we give a short description of the areas of standardization:

system architecture:	Description of the general structure of a (software) system, its components, the interdependencies between these components, rules to generate these components, and internal and external interfaces.
data dictionary:	A kind of lexicon, containing a static description of the data that are relevant for an application domain.
data model:	An abstract model of a part of the real world, encompassing the relevant entities, their attributes and relations.
data bases:	Pool of data, usually the content of a data base system, and based on a certain data model.
fidelity of algorithms:	The algorithms that are used within M&S, are often proprietary and will not be disclosed. But to assure e.g. causality or fair fight between different simulation systems, measures have to be found to compare the outcomes of different algorithms under the aspects of credibility and correctness.
modularity:	A module is a functional unit with a specified interface. New systems can be built up by using existing modules.
middleware:	Communication software, that is used by application programs for communication and data access in a distributed environment.
requirements specification:	Comprises the analysis of user needs, or the definition of the problem space, and can be formulated e.g. by use cases.
process model:	A description of all activities and the expected results during the development of a system. A process model is an essential prerequisite e.g. for quality assurance or VV&A.
interface definition:	Complete description of the data exchange mechanism between different systems or modules.
DIF:	Data Interchange Format. Storage format for data files that are exchanged between different application programs.
MMI, GUI:	Man Machine Interface, Graphical User Interface.
accessibility:	Open access to software or data. In addition, support of different platforms, absence of proprietary or security restrictions etc.
proprietary rights:	Restrictions to the use of software, data bases, systems etc. due to legal and/or commercial reasons. Even more severe is the fear to lose know-how to competitors.
repository:	A structure and a tool (e.g. a data warehouse) to store information about models, simulations, databases etc. The information might be technical and administrative in nature.
configuration management:	The administration of source codes, data, documentation, and other ingredients of systems, including release control.
criticality assessment:	For application domains: a measure of the risk associated with an intended application. Closely connected with VV&A.
credibility assessment:	For M&S elements: a measure of accuracy and assurance associated with the M&S element (e.g. a simulation system or a database). Closely connected with VV&A.
documentation:	A systematic, complete description of all information that is relevant for the development or for the use of a system.

Other areas of standardization which might be considered as being relevant for standardization have been omitted because they are included in one or several of the above mentioned areas (e.g.: APIs are part of modularity, middleware, and interface definition; protocols are part of interface definition; VV&A is part of process models and credibility assessment).

Some areas of standardization apply to more than one requirement for simulations, and the areas are of different importance. Similar to table 1a, where the requirements for simulations and other M&S elements are connected to the superior goals for M&S employment, we summarize the connections between areas of standardization and requirements for simulations and other M&S elements in table 2.

In table 2, we give an estimation of the importance which a specific area of standardization has for a specific requirement (again, the values are semi-quantitative, and the scale runs from 0: no significant importance, up to 5: very high importance).

area of standardization	requirements for M&S elements			
	re-usability	interoperability	usability	credibility
system architecture	5	5	3	0
data dictionaries	4	4	2	1
data models	5	5	2	1
data bases (e.g. environment)	5	5	2	1
fidelity of algorithms	5	5	2	0
modularity	5	4	2	1
middleware	5	5	2	0
requirements specification	4	4	4	2
process models (incl. VV&A)	4	4	3	5
interface definitions	5	5	2	0
DIFs	3	5	2	0
MMI, GUI	2	0	5	0
accessibility	2	2	5	0
proprietary rights	1	1	5	0
criticality assessment	3	3	1	5
credibility assessment	3	3	2	5
repository	2	2	3	0
configuration management	2	2	3	0
documentation	4	4	4	4

Table 2: Importance of areas of standardization for requirements for M&S elements (0: no significant importance, 5: very high importance).

The importance of a certain area of standardization for reaching a specific superior goal for M&S employment can now be deduced from tables 1b and 2, by performing weighted sums over the rows in table 2, and using the entries in table 1b as weights. The results are shown in table 3 (example: the importance of the area of standardization *fidelity of algorithms* for the superior goal *minimization of acquisition time* is $0.33 * 5 + 0.27 * 5 + 0.20 * 2 + 0.20 * 0 = 3.40$).

An appropriate measure for the overall importance of a certain area of standardization could be the sum over the importance values. Therefore, in the column *sum* of table 3, the entries for an area of standardization are summed over the superior goals.

The superior goals *minimization of risk*, *optimization of system requirements* and *optimization of system behaviour* are all deduced from the original goal *maximization of acquisition quality*. Under the assumption, that the three original goals (cost, time, and quality) are equally important, one has to introduce weights before performing sums. An adequate choice are the weights 1, 1, 1/3, 1/3 and 1/3 for the superior goals, as listed in table 3. In the last column of table 3, the weighted sums are shown.

The rows in table 3 are sorted by decreasing weighted sums. A sorting by simple sums would only lead to minor changes in the order of rows.

The following observations are in order:

1. The importance values in table 3 are derived directly from the entries in table 1 and 2, and the detailed results of table 3 depend from the estimations in table 1 and 2. Of course, these estimations are quite debatable, and thus the results as shown in table 3 are rather vague in nature.
2. Nevertheless, the areas of standardization can now be easily divided into groups with decreasing importance, according to the weighted sums. If we take 1/2 and 3/4 of the maximum value (i.e. about 12) as dividing lines, we get three groups of areas of standardization with decreasing importance (the separations are indicated in table 3 by stronger horizontal lines):
    a. The first group with highest importance comprises 8 areas of standardization. Most of these areas have something to do with VV&A: process models, documentation, requirements specification, credibility and criticality assessment are all directly linked to VV&A.
    b. The second group comprises 7 areas of standardization.
    c. The third group with lowest importance contains the remaining 4 areas.

In table 4, the areas of standardization are sorted by decreasing importance for the different superior goals for simulation employment. There are only slight changes in the order of the areas of standardization between the different superior goals.

area of standardization	superior goals for M&S employment						
	minim. of costs	minim. of time	minim. of risk	optim. of requirem.	optim. of system beh.	sum	**weighted sum**
process models (incl. VV&A)	3.89	4.00	4.27	4.00	4.17	20.33	**12.04**
documentation	4.00	4.00	4.00	4.00	4.00	20.00	**12.00**
requirements specification	3.67	3.60	3.09	3.14	3.00	16.50	**10.34**
credibility assessment	3.06	3.20	3.73	3.43	3.67	17.08	**9.86**
data models	3.50	3.60	2.64	2.00	2.00	13.74	**9.31**
data bases (e.g. environment)	3.50	3.60	2.64	2.00	2.00	13.74	**9.31**
system architecture	3.61	3.60	2.36	2.00	1.83	13.41	**9.28**
criticality assessment	2.78	3.00	3.55	3.00	3.33	15.66	**9.07**
modularity	3.22	3.33	2.45	1.86	1.83	12.70	**8.60**
fidelity of algorithms	3.33	3.40	2.18	1.57	1.50	11.99	**8.48**
middleware	3.33	3.40	2.18	1.57	1.50	11.99	**8.48**
interface definitions	3.33	3.40	2.18	1.57	1.50	11.99	**8.48**
data dictionaries	2.94	3.00	2.27	1.86	1.83	11.91	**7.93**
DIFs	2.78	2.73	1.82	1.57	1.50	10.40	**7.14**
accessibility	2.50	2.20	1.64	2.43	2.00	10.76	**6.72**
proprietary rights	1.94	1.60	1.27	2.29	1.83	8.94	**5.34**
MMI, GUI	1.94	1.67	1.27	2.14	1.67	8.69	**5.31**
configuration management	1.94	1.80	1.27	1.57	1.33	7.92	**5.14**
repository	1.94	1.80	1.27	1.57	1.33	7.92	**5.14**

Table 3: Importance of areas of standardization for reaching superior goals for M&S employment (the entries are computed from tables 1 and 2, increasing numbers mean increasing importance). See text for details.

minim. of costs	*minim. of time*	*minim. of risk*	*optim. of requirem.*	*optim. of system beh.*
documentation	documentation	process models (incl. VV&A)	process models (incl. VV&A)	process models (incl. VV&A)
process models (incl. VV&A)	process models (incl. VV&A)	documentation	documentation	documentation
requirements specification	requirements specification	credibility assessment	credibility assessment	credibility assessment
system architecture	system architecture	criticality assessment	requirements specification	criticality assessment
data models	data models	requirements specification	criticality assessment	requirements specification
data bases (e.g. environment)	data bases (e.g. environment)	data models	accessibility	accessibility
fidelity of algorithms	fidelity of algorithms	data bases (e.g. environment)	proprietary rights	data models
middleware	middleware	modularity	MMI, GUI	data bases (e.g. environment)
interface definitions	interface definitions	system architecture	data models	proprietary rights
modularity	modularity	data dictionaries	data bases (e.g. environment)	system architecture
credibility assessment	credibility assessment	fidelity of algorithms	system architecture	modularity
data dictionaries	data dictionaries	middleware	modularity	data dictionaries
criticality assessment	criticality assessment	interface definitions	data dictionaries	MMI, GUI
DIFs	DIFs	DIFs	fidelity of algorithms	fidelity of algorithms
accessibility	accessibility	accessibility	middleware	middleware
proprietary rights	configuration management	configuration management	interface definitions	interface definitions
MMI, GUI	repository	repository	DIFs	DIFs
configuration management	MMI, GUI	MMI, GUI	configuration management	configuration management
repository	proprietary rights	proprietary rights	repository	repository

Table 4: Areas of standardization, sorted by decreasing importance for the superior goals for M&S employment.

3 Overview on existing standards

In this chapter an overview on existing standards, either established or proposed, that are already in use within the defense M&S community, will be given. These standards are:

1. ALSP
2. DIS
3. HLA
4. CORBA
5. RPR FOM
6. FEDEP
7. UML

8. OpenFlight
9. SEDRIS
10. ATCCIS
11. NC3DM

For each standard, a short description will be given, followed by a discussion of the extent to that it possibly could be used, and its deficiencies.

3.1 ALSP

The *Aggregate Level Simulation Protocol* (ALSP) [8] is both, software and a protocol. It is used to enable disparate simulations to communicate with one another. The use of ALSP is limited to large constructive simulations, as employed especially in computer assisted exercises (CAX).

The development of ALSP began in 1990, initiated by the Defense Advanced Research Projects Agency (DARPA). In 1992, an ALSP Confederation supported major exercises for the first time.

The US community for ALSP is the *Joint Training Confederation* (JTC). Data are exchanged as ASCII strings via reliable transport mechanisms.

Deficiencies of ALSP are:

1. Time management only for event-driven simulations, no real-time capability.
2. Inflexible handling of object types.
3. Performance of the ALSP Infrastructure Software (AIS) can become critical.
4. ALSP is not an officially established and not even an open standard.

3.2 DIS

The *Distributed Interactive Simulation* (DIS) is both the name of a technique and a communications protocol [9]. The concept of DIS came from an idea germinating in the early 1980’s that postulated linking together training simulators to create a shared simulated environment.

DIS defines *Protocol Data Units* (PDU) with fixed formats for the information exchange between the simulators using best effort transport mechanism.

DIS is an established set of IEEE-standards (IEEE 1278).

Deficiencies of DIS are:

1. No time management for event-driven simulations (in the first standard IEEE 1278.1-1995).
2. Not suited for simulation systems other than training simulators (in the first standard IEEE 1278.1-1995).
3. Inflexible due to strong cohesion between data and architecture (fixed data model).
4. Performance can become critical if the number of involved simulators exceeds certain limits.
5. No guaranteed causality.
6. No standard API, no standard software.
7. Industry often uses extensions to the standard.

3.3 HLA

The High Level Architecture (HLA) [10], [11], [12] is a general purpose architecture for simulation reuse and interoperability. The HLA was developed under the leadership of the Defense Modeling and Simulation Office (DMSO) as an essential part of the *Common Technical Framework* (CTF), in accordance with the US M&S Master Plan. The CTF was created to facilitate the interoperability of all types of models and simulations among themselves and with C3I systems, and to facilitate the reuse of M&S components.

The HLA Baseline Definition was completed in 1996. Since September 2000, HLA is an established IEEE standard (IEEE 1516). It has also been accepted as the M&S architecture for NATO.

The High Level Architecture is defined by three documents: the HLA Rules, the HLA Interface Specification , and the HLA Object Model Template (OMT).

While the HLA is an architecture, not software, the use of a HLA-compliant implementation of a runtime infrastructure (RTI) software is required to support the operation of a federation execution. The RTI software provides a set of services used by federates to coordinate their operations and data exchange during a runtime execution. Access to these services is defined by the HLA Interface Specification.

The HLA doesn’t define data models. Instead the users must agree upon a Federation Object Model (FOM) that has to be defined using a specific interchange format called the Object Model Template (OMT). Each federate must define a Simulation Object Model (SOM) – usually a subset of the FOM – that specifies its contribution to or interest in the federation.

HLA allows to communicate – different from DIS – only the changes of objects via the RTI using best effort or reliable transport mechanism.

The use of HLA is spreading. HLA is on the way to replace the older standards ALSP and DIS.

Deficiencies of HLA are:

1. OMT does not cover all aspects of interoperability of simulations (e.g. algorithms).
2. Communication between RTIs of different vendors on the wire is not possible because of lack of standards.
3. Performance can became critical.

3.4 CORBA

CORBA (Common Object Request Broker Architecture) is an open distributed object computing infrastructure. CORBA automates many common network programming tasks such as object registration, location and activation, and error handling. Using a standard protocol, a CORBA-based program can interoperate with another CORBA-based program, independent from the differences in operating systems, programming languages, and network protocols [13], [14].

CORBA’s architecture is based on object oriented design, and built around three key building blocks:

1. the Object Request Broker (ORB),
2. the Interface Definition Language (IDL), and
3. the Internet Inter-ORB Protocol (IIOP).

The ORB provides a mechanism for transparently communicating client requests to target object implementations. When a client invokes an operation, the ORB is responsible for finding the object implementation, activating it, delivering the request to the object, and returning any response to the calling client.

The IDL lets developers define interfaces to their programs and objects in a standardized fashion. The IDL definitions and types are mapped to programming languages such as C, C++, Java and Ada.

The IIOP is a standardized protocol that the ORBs use for the seamless communication with other ORBs, even from different vendors.

CORBA is standardized by the OMG (Object Management Group), an open membership, not-for-profit consortium that produces and maintains computer industry specifications for interoperable enterprise applications. The OMG was founded in 1989 by 8 companies, including e.g. Hewlett-Packard and Philips, and has now about 800 members, including virtually every large company in the computer industry, and hundreds of smaller ones [13].

CORBA 1.0 was released 1991. CORBA 2.0 included the IIOP and was released in 1994, CORBA 3.0 in 1999.

Deficiencies of CORBA are:

1. Despite the fact that the CORBA-standards are public, most of the implementations (e.g. the ORBs) are commercial products.
2. Building applications with CORBA requires special expertise.
3. In contrast to HLA, CORBA is missing a proper time management.

3.5 RPR FOM

The Real-time Platform Reference Federation Object Model (RPR FOM) [12] was designed to organize the attributes and interactions of DIS into a robust HLA object hierarchy. Thus, the PDUs were mapped onto HLA classes and interactions making only little use of object oriented design. This conservative approach to a standardized data model for virtual simulations will definitely ease the transition of DIS compliant simulations to HLA.

The priorities for developing this design are, in order:

1. Support transition of legacy DIS systems to the HLA.
2. Enhance a-priori interoperability among RPR FOM users.
3. Support newly developed federates with similar requirements.

Like DIS, the RPR FOM is designed to support real time simulations where the principal participants are discrete physical entities such as planes, ships, soldiers, and munitions.

Version 1.0 of the RPR FOM is designed to provide an HLA conversion path for the full suite of DIS capabilities as defined in IEEE 1278.1-1995. Version 2.0 of the RPR FOM will add the functionality of the IEEE 1278.1A-1998 standard and will be compliant with the IEEE 1516 HLA standard.

3.6 FEDEP

The purpose of the FEDEP (Federation Development and Execution Process) [15] is to describe a generalized process for building and executing HLA federations. It is intended to provide a high-level framework for HLA federation construction into which lower-level development practices can be easily integrated. The FEDEP defines a generic systems engineering methodology for HLA federations that can and should be tailored to meet the needs of individual applications.

It was recognized that the actual process used to develop and execute HLA federations could vary significantly within or across different user applications. However, at a more abstract level, it is possible to identify a sequence of six very basic steps that have to be followed during the development and execution of HLA federations:

Step 1: Define Federation Objectives.

Step 2: Develop Federation Conceptual Model.

Step 3: Design Federation.

Step 4: Develop Federation.

Step 5: Integrate and Test Federation.

Step 6: Execute Federation and Prepare Results.

The FEDEP describes a decomposition of each of these six major steps into a set of interrelated lower-level activities and supporting information resources.

The standardization of FEDEP by SISO started in spring 2001, by founding a PDG (Product Development Group) according to the SISO rules. FEDEP shall became an IEEE standard (IEEE 1516.3) at the end of 2001.

3.7 UML

The Unified Modeling Language (UML) is an open, nonproprietary standard. It is a visual modeling language for building object-oriented and component-based systems, and is used for specifying, constructing, visualizing, and documenting the artifacts of a software-intensive system [13].

The main elements of the UML are:

- use case diagrams,
- class diagrams,
- behaviour diagrams (encompassing statechart, activity and interaction diagrams), and
- implementation diagrams (encompassing component and deployment diagrams)

Although the UML is a visual modeling language, it is not intended to be a visual programming language, and the UML does not prescribe a standard process.

The development of UML began in late 1994 when G. Booch and J. Rumbaugh of Rational Software Corporation began their work on unifying the Booch and OMT (Object Modeling Technique) methods. In the fall of 1995, I. Jacobson and his Objectory company joined Rational and this unification effort, merging in the OOSE (Object-Oriented Software Engineering) method. UML 1.0 was submitted to the OMG in January 1997. The present version is 1.3. UML 2.0 is under development.

3.8 OpenFlight

OpenFlight is a open standard realtime 3D file format. Developed by MultiGen-Paradigm [16], is it now in the public domain and the de facto standard in the visual simulation industry. OpenFlight scene description databases are complete, cross-platform hierarchical structures.

The OpenFlight database format supports both simple and relatively sophisticated realtime software applications. It supports multiple levels of detail, replication, animation sequences, real time culling, scene lighting features, transparency, texture mapping, material properties, and other features.

3.9 SEDRIS

As its name implies, SEDRIS (Synthetic Environment Data Representation and Interchange Specification) [10], [17] is fundamentally about two key aspects: (1) the representation of environmental data, and (2) the interchange of environmental data sets.

SEDRIS is an infrastructure technology. It provides the enabling foundation for IT applications to express, understand, share, and reuse environmental data.

The SEDRIS Objectives are to:

- Articulate and capture the complete set of data elements and associated relationships needed to fully represent the physical environment.
- Support the full range of simulation applications (e.g., computer-generated forces, manned, visual, and sensor systems) across all environmental domains (terrain, ocean, atmosphere, and space).
- Provide a standard interchange mechanism to pre-distribute environmental data (from primary source data providers and existing resource repositories) and promote data base reuse and interoperability among heterogeneous simulations.

In order to support the unambiguous *description* of environmental data, SEDRIS specifies both a Data Representation Model (DRM) and an Environment Data Coding Specification (EDCS). In order to support the unambiguous and lossless *interchange* of environmental data, SEDRIS specifies a Spatial Reference Model (SRM) including a set of inter-related spatial reference frames with respect to which all environmental data is referenced.

In October 1999, SEDRIS began the process of establishing international standards through the combined International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). Currently, there are two working drafts for proposed standard nominations: ISO/IEC WD 18025 for EDCS and ISO/IEC WD 18026 for SRM [11].

3.10 ATCCIS

The *Army Tactical Command and Control Information System* (ATCCIS) [18] study is an international programme that aims to identify the minimum set of specifications, to be included within Command and Control (C2) systems, to allow interoperability of multi-national C2 systems.

The ATCCIS concept of interoperability is based on the automatic transfer of standardized data elements that utilize agreed and common data identifiers based on a common data interchange model. The common data model is known as the Land C2 Information Exchange Data Model, formerly called the ATCCIS Battlefield Generic Hub Data Model.

The first phase of the ATCCIS study began in 1980. Currently, the ATCCIS products shall be proposed for adoption as NATO Standards (Draft STANAG 5523 or ADatP-32).

3.11 NC3DM

The *NATO C3 Data Model* (NC3DM) [19] is a generic data model designed to provide a data structure that can hold all of the information needs of the intended users. This information needs constitute every thing that may contribute to a rich picture of an area of operations.

With NC3DM, a „virtual database“ is available which contains data about any areas of operation with which NATO is concerned. The scope and level of detail supported by this „virtual database“ is limited only by the range of information supplied. Information available to C3 commanders and their staff is obtained from any of numerous real databases, each of which is a physical representation of some of the rows within this NATO-wide „virtual database“.

When populated as described above the NC3DM provides unique identification of all data available to C3 commanders and their staff with descriptions that are explicit and unambiguous whether they form part of agreed NATO standards or are recognized only by an individual nation, sector or application. There are three distinct ways in which this comprehensive „virtual database“ can contribute to the interoperability of the computerized information systems of NATO commands and member nations as follows:

a. As a basis for information exchange.

b. As a basis for database design.

c. As a facilitator for data standardization.

4 Adaptation and further development of standards

4.1 Summary on existing standards

In table 5, the existing standards, as described in section 3, are compared to the areas of standardization, as identified in section 2.4 of this report. It is indicated when a standard is fully applicable for a certain area of standardization, or might at least contribute to a certain area of standardization.

It follows from table 5, that only a part of the areas of standardization is currently supported by standards.

4.2 Missing essential standards for M&S

There are several important areas of standardization in table 5 without a standard.

If we exclude those areas which are not very specific for M&S, the following areas of standardization (with decreasing importance) are remaining:

1. credibility assessment,
2. criticality assessment, and
3. fidelity of algorithms.

These areas have been described shortly in section 2.4. Quite strikingly, they are all directly linked to VV&A.

Since all these areas have rather high importance values (cp. table 3 in section 2.4) they must be supported by standardizations in the future.

	existing standards										
area of standardization	ALSP	DIS (IEEE 1278)	HLA (IEEE 1516)	CORBA	RPR FOM	FEDEP	UML	OpenFlight	SEDRIS	ATCCIS	NC3DM
process models (incl. VV&A)						X					
documentation						(X)	(X)				
requirements specification							(X)				
credibility assessment											
data models	(X)	X	(X)		X		(X)			X	X
data bases (e.g. environment)								(X)	(X)	(X)	
system architecture			X	X			(X)				
criticality assessment											
modularity							(X)				
fidelity of algorithms											
middleware	X		(X)	X							
interface definitions	(X)	(X)	(X)	(X)			(X)				
data dictionaries					(X)					(X)	(X)
DIFs								X	X		
accessibility											
proprietary rights											
MMI, GUI											
configuration management											
repository											

Table 5: Areas of standardization vs. existing standards. Crosses indicate when a standard is fully applicable for a certain area of standardization. Crosses in brackets indicate when a standard might contribute to a certain area of standardization. The areas of standardization are sorted by decreasing importance (cp. table 3).

5 Feasibility of missing essential standards

5.1 Organizational implications

The successful implementation of a new standard requires:

- a need for the standard, as expressed by the user community (which consists of governmental representatives, industry and academia),
- an open discussion within the user community about the technical details of the standard,
- support through tools, guides, recommended practices etc.

A good example for the organizational handling of the development and introduction of new standards are the procedures that have been developed by SISO [20]:

1. The operating principles of SISO in standards development include openness, consensus, generality, stability and supportability.
2. The development of standards and related products is done in a well defined Product Development Process. At a high level, this Product Development Process consists of 4 steps:
   - issue identification,
   - product evaluation and evolution,
   - balloting,
   - configuration management and re-certification.

Quite similar is the definition of the Standards Development Process for the US Army [2]. This process consists of 7 steps:

1. Build Team
2. Define Requirements
3. Develop Standards
4. Achieve Consensus
5. Obtain Approval
6. Promulgate Standards
7. Educate

All these procedures don't require a special infrastructure; it can be taken for granted that the infrastructure that is already available within the M&S-community, is fully sufficient for the purpose of developing and introducing new standards.

5.2 Cost implications

The Return On Investment (ROI) for standards in general terms is quite elusive and difficult to quantify. So, in this section, we will just give an overview of cost factors (costs and benefits) that are associated with the use and implementation of standards in the field of M&S (cp. to similar discussion in [4]).

Costs:

- capital costs, e.g. for licenses
- development of tools, guides etc. that support the use of a standard
- investment in M&S-applications to use a standard
- training of developers and decision makers

(To this, the costs for creating a standard must be added. But these are extremely elusive since most of the work will be done in informal meetings or workshops.)

Benefits:

- manpower saving due to the use of standards
- quicker delivery due to the use of standards

In summary, it could be said that the introduction and use of a new standard should lead to a reduction of costs. This is true at least after the general adaptation of the new standard has taken place (working-in phase), and for the implementation of the new standard into new systems.

A cost-driver could be the adaptation of old systems to a new standard. This should be done only if there is a really urgent need to do so, e.g. due to interface requirements.

6 Discussions with interested parties

Early versions of this report have been presented to representatives of the German simulation industry and other interested parties. The emerging discussions have lead to useful insights and contributions to this report. There was a broad consensus concerning the main points of this report. The details are of course under the responsibility of the authors.

1. The first discussion took place at STN ATLAS Elektronik GmbH in Bremen on 19 February 2001. The main points raised were proprietary rights, requirements specification, fidelity of algorithms, middleware, and DIF.
2. On 8 March 2001 a discussion took place at the Heeresamt (Army Office) in Köln, department V (3). The discussion centered mainly about general aspects of standardization for M&S.
3. On 22 March 2001 a discussion took place at ESG GmbH in Munich. Main points were databases, MMI and system architecture.
4. On 11 April 2001 a discussion took place at IABG in Munich. Main points were basic considerations, proprietary rights, and fidelity of algorithms.
5. On 27 April 2001 a discussion took place at CAE Elektronik GmbH in Stolberg. Main points were documentation and requirements specification.

7 Conclusions

There is an obvious need for standards in the field of M&S: interoperability and re-usability of simulation systems or other M&S-elements are just the most striking examples. As the discussions with representatives of the German simulation industry have shown, there is a broad consensus about the usefulness of standards in general. But the acceptance of a specific standard depends critically on its particular value for solving the complex problems which are associated with M&S-projects.

Thus new standards for M&S have to be found in a well-defined procedure that is open to all interested parties: government, industry and academia. The procedures that have been developed by SISO are a good example. NATO should consider either to join the SISO-efforts in a more substantial way or to set up own, similar procedures.

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9 Abbreviations

AIS	ALSP Infrastructure Software
ALSP	Aggregate Level Simulation Protocol
API	Application Programming Interface
ATCCIS	Army Tactical Command and Control Information System
CAX	Computer Assisted Exercise
CPM	Costumer-Product-Management
CORBA	Common Object Request Broker Architecture
C2	Command and Control

C3	Command, Control and Communication
C3I	Command, Control, Communication and Intelligence
DIF	Data Interchange Format
DIS	Distributed Interactive Simulation
DMSO	Defense Modeling and Simulation Office
DoD	Department of Defense
DRM	Data Representation Model
DST	Decision support tool
EDCS	Environment Data Coding Specification
FEDEP	Federation Development and Execution Process
FOM	Federation Object Model
GUI	Graphical User Interface
HLA	High Level Architecture
IDL	Interface Definition Language
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IIOP	Internet Inter-ORB Protocol
ISO	International Organization for Standardization
MMI	Man Machine Interface
M&S	Modelling and Simulation
MSG	Modelling and Simulation Group
NC3DM	NATO C3 Data Model
OMG	Object Management Group
OR	Operations Research
ORB	Object Request Broker
RPR	Real-time Platform Reference
RTI	Runtime Infrastructure
SBA	Simulation Based Acquisition
SBDVP	Simulation Based Design and Virtual Prototyping
SEDRIS	Synthetic Environment Data Representation and Interchange Specification
SISO	Simulation Interoperability Standards Organization
SRM	Spatial Reference Model
TAP	Technical Activity Program
ToR	Terms of Reference
VV&A	Verification, Validation and Accreditation

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Generic Toolbox for Interoperable Systems – GTI6
Environnement modulaire pour l'interopérabilité des systèmes – GTI6

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Un environnement générique pour l'interopérabilité des systèmes (GTI6) [6] a été développé par EADS LAUNCH VEHICLES (EADS LV) pour améliorer la qualité et l'efficacité de ses processus industriels. En tant que maître d'œuvre de différents lanceurs et véhicules spatiaux tels que Ariane 5 ou l'ATV (Automated Transfer Vehicle), EADS LV a besoin de réaliser de longues études et de construire d'importantes et complexes installations de simulation pour accompagner toutes les phases du cycle de vie de ses nouveaux systèmes : définition des exigences, analyses de faisabilité, définition de l'architecture, développement, intégration, qualification, production, opération… Aujourd'hui, les nouvelles technologies de l'information permettent d'effectuer la plupart de ces tâches par des équipes géographiquement distribuées afin de :

- Partager rapidement les informations et les données entre équipes distantes,
- Utiliser des ressources distantes de manière interactive, favorisant ainsi la flexibilité et l'efficacité du travail,
- Diminuer la durée du cycle de vie des nouveaux systèmes en anticipant la détection des problèmes de conception, d'intégration et de mise en œuvre,
- Améliorer la qualité globale du système,
- Minimiser les voyages et les longs détachements d'experts
- Réduire le coût global des installations par la non-duplication de composants, de connaissances et de compétences des équipes

GTI6 contribue aussi bien aux tâches d'analyse technique collaborative entre équipes distantes, qu'à l'interopérabilité entre des installations géographiquement distribuées de simulation, de modélisation, de traitement et de post-traitement.
En premier lieu, cet article présente le concept et l'architecture GTI6, puis quelques applications typiques et des résultats. Enfin, quelques recommandations générales sont proposées à propos de l'interopérabilité entre systèmes distribués. Les perspectives pour étendre l'utilisation de GTI6 à d'autres domaines sont aussi évoquées.

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A Generic Toolbox for Interoperable Systems (GTI6) [6] has been developed by EADS LAUNCH VEHICLES (EADS LV) for improving the quality and the efficiency of its industrial processes. As prime contractor of various launchers and spacecrafts such as Ariane 5 or the Automated Transfer Vehicle (ATV), EADS LV needs to perform long studies and to build huge and complex simulation facilities all along the life-cycle phases of its new systems: requirements definition, feasibility analyses, architecture design, development, integration, qualification, production, operation... Nowadays, new Information Technologies allow to perform most of these tasks in a geographically distributed way in order:

- to quickly share information and data between distant teams,
- to interactively use remote resources, making the work more flexible and efficient,
- to shorten the life-cycle duration of new systems by anticipating detection of design, integration or operational problems,
- to improve the global quality of the system,
- to minimize travels and long collocation of experts,
- to reduce facilities overall costs by non-duplication of components, teams knowledge and skills,

GTI6 supports collaborative engineering analysis between distant team, as well as interoperability between geographically distributed facilities for simulation, modelling, processing and post-processing.
First of all, this paper will present the GTI6 concept and architecture, then some typical applications and results. At the end, some general recommendations will be proposed regarding the interoperability between distributed systems. The current plan to extend the use of GTI6 to other domains will also be described.

ARTICLE

Introduction

EADS LAUNCH VEHICLES is the prime contractor of various launchers and spacecrafts such as Ariane 5 or the Automated Transfer Vehicle (ATV). In this context, EADS LV needs to perform long engineering studies and also to build huge and complex simulation facilities all along the life-cycle phases of its new systems: requirements definition, feasibility analysis, architecture design, development, integration, qualification, operation... An effective environment to support large-scale application of collaborative engineering platforms is now a common need in the current frame of closer and closer collaborations among the European Space Agencies and Industries, while the new Information Technologies allow to perform most of the above tasks in a geographically distributed way, with the following advantages:

- to quickly share information and data between distant teams,
- to take advantage of synergy/opinions of the various groups and different specialists
- to interactively use remote resources, making the work more flexible and efficient,
- to shorten the life-cycle duration of new systems by early involvement of different teams, from suppliers and sub-contractors to end-users, in a cross disciplinary
- to early detect engineering bottlenecks in the design, integration and operations of new systems allowing the identification and implementation of technical as well as managerial solutions
- to improve the global quality of the system,
- to minimise travels and long collocation of experts,
- to reduce facilities overall costs by non-duplication of components, teams knowledge and skills,

In this context, EADS LV started to develop a Generic Toolbox for Interoperable Systems (GTI6) for improving the quality and the efficiency of its industrial processes. This toolbox supports collaborative engineering analysis between distant team, as well as interoperability between geographically distributed facilities for simulation, modelling, processing and post-processing.

The GTI6 concept

Generally speaking, each life-cycle phase of any system can be associated to the concepts of geographical distribution and interoperability. Moreover numerous people with different levels of responsibilities are usually involved in these phases and can consequently benefit from the distribution paradigm, system engineers, software engineers, quality engineers, project managers, program managers, customers, subcontractors... For each phase of the life-cycle, the following table indicates some tasks that can be geographically distributed:

<table>
<tr><th>Phase</th><th>Distributed Tasks</th></tr>
<tr><td>Requirements Definition</td><td>- Collaborative Requirements Analysis
- Shared Requirements Database
- Shared Requirements Analysis Tools
- Shared Knowledge Tools</td></tr>
<tr><td>Feasibility Analysis</td><td>- Distributed Virtual Mock-Up
- Shared Knowledge Tools</td></tr>
<tr><td>System Design</td><td>- Collaborative Design Analysis
- Distributed Interactive Engineering Simulation
- Shared Design Database
- Shared Design Analysis Tools</td></tr>
<tr><td>Review</td><td>- Collaborative Review Process
- Shared System Documentation
- Shared Review Database
- Shared Analysis Tool</td></tr>
<tr><td>Development</td><td>- Shared Product Database
- Shared Configuration Management</td></tr>
<tr><td>Integration</td><td rowspan="3">- Distributed Interactive Functional Simulation
- Shared Test and Results Database
- Collaborative Test Preparation (pre-processing)
- Collaborative Results Analysis (post-processing)</td></tr>
<tr><td>Validation</td></tr>
<tr><td>Qualification</td></tr>
<tr><td>Operation</td><td>- Distributed Interactive Operational Simulation
- Shared Mission Database
- Collaborative Mission Preparation
- Collaborative Mission Rehearsal and Training
- Shared technical support and tele maintenance</td></tr>
</table>

The purpose of GTI6 is to support such distributed tasks by providing the necessary tools in order:

- to allow collaborative working between distant teams,
- to manage the shared engineering databases,
- to interconnect in real time or faster than real-time the distributed simulation facilities

The GTI6 architecture

The GTI6 is a modular package containing 9 generic components, which can be totally or partially used for any kind of distributed and interoperable systems.

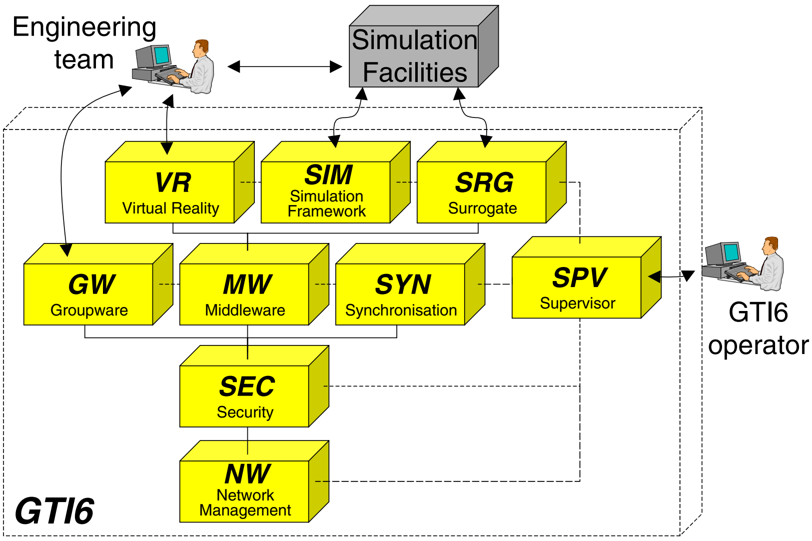

Figure 1 : *GTI6 Architecture.*

GTI6 – MW (Middleware)

The Middleware is a core element in the GTI6 architecture as it lies between the Simulation Framework, the Surrogate, the Supervisor, the Synchronisation and the Network and Security services. The Middleware comprises the following components:

- The Run-Time Infrastructure respecting the HLA interface specification [2].
- The Dead-Reckoning Library (DR) providing prediction algorithms to hide the network latency.
- The Base Object Models (BOM) providing a re-usable object model enabling all components of
- the Middleware and GTI6 applications to communicate.
- The Simulation Management Library (SM) providing services needed to manage the GTI6 federations.
- The XDR (eXternal Data Representation) Library providing cross-platform compatibility of HLA federation data.

The above middleware components had been developed for SGI IRIX 6.5 and PC NT 4.0 platforms.

GTI6 – GW (Groupware)

The Groupware is based on the MBONE tools such as VIC, RAT and WBD. These tools have been selected for providing video, audio and shared workspace functionality. They are operable both in point-to-point and multicast modes, in the latter they are using the multicast service provided by the GTI6 communication services.

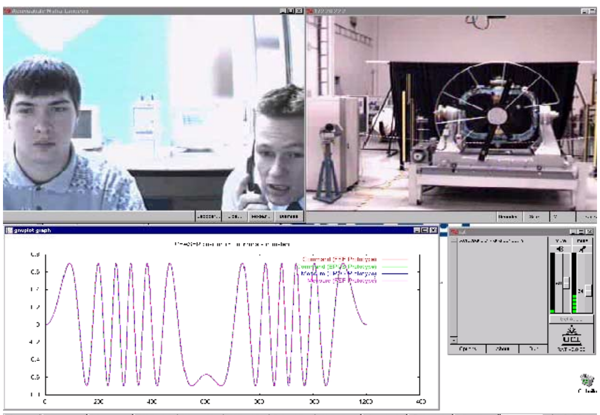

Figure 2 : *GTI6 Groupware.*

GTI6 – SPV (Supervisor)

The GTI6 Supervisor provides setting up the whole distributed environment and configuring all the necessary services. It incorporates the following components available for the GTI6 operator:

- Configuration information panel
- Network topology view
- Network status panel
- Ping tool
- SNMP browser
- Traffic viewer
- Simulation control window
- Federate status panel.

The Supervisor GUI was developed in Java language, which facilitates easy development of platform-independent GUIs. Supervisor agents could be deployed on all the stations participating in the exercise through the network, in order to control and to monitor the entire environment.

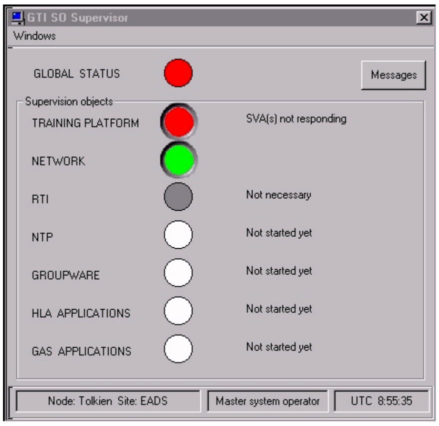

Figure 3 : *GTI6 Supervisor.*

GTI6 – NW (Network Manager)

The communication services hide a wide-area network (WAN) from the middleware and groupware. The control and monitoring of the communication services, and thus also the WAN, is done by the GTI6 Supervisor. The communication services are using the TCP/IP protocol suite over the WAN and provide separated network services to the middleware and groupware.

The GTI6 Network Management provides the following:

- Quality of Service (QoS) management based on “Differentiated Services” (according to the IETF terminology [4]: diff-serv)
- Network Monitoring and Configuration Access to the WAN edge devices. It is provided by means of the SNMP protocol [5]. The SNMP application integrated with the Supervisor is used to monitor the network on the WAN termination devices. QoS measurements (i.e. packet round trip time, packet loss, throughput measurements, traffic) are provided by the communication framework through the ICMP protocol.
- The IP multicast service is provided by the GTI6 Network Management by interfacing between the supervisor and the multicast configuration on the WAN edge devices, if these are Cisco routers, or by the configuration of the mrouted daemon process on the end-systems. The mtrace tool is provided to support monitoring of the IP multicast service.

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GTI6 – SYN (Time Synchronisation)

In most of distributed simulation systems, it is essential to get a precise time synchronisation between all the computers participating to the exercise. This is the duty of the GTI6 Synchronisation. It is achieved

firstly by using an accurate Time Server, either based on a GPS clock or on other precise time source, secondly by using the NTP synchronisation toolkit (Network Time Protocol) based on the RFC 1305 standard [3] and customised to meet the GTI6 specific requirements.

GTI6 – VR (Virtual Reality)

The GTI6 VR is a framework intended for visualisation rendering of a distributed simulation scene. It is implemented as an HLA compliant stand-alone application that can be a federate in any GTI6 federation.

The scene can contain several objects, both static and dynamic. Many types of objects can be integrated: simple geometrical objects, complex hierarchy of interrelated objects and lights. The scene organises these objects hierarchically and can attach dynamic attributes to these objects. Various dynamic attributes are defined in the GTI6 Visualisation BOM and come from the RTI.

Once a connection to an HLA federation is established, any objects discovered through the RTI are automatically created in the scene, displayed and monitored. Any change in their attributes (position, orientation, etc) becomes immediately apparent in the VR display.

Additionally, geographically distant users of the VR framework who are part of the same federation can share their virtual cameras. The VR framework is thus an integrated part of the set of collaborative work tools provided by GTI6.

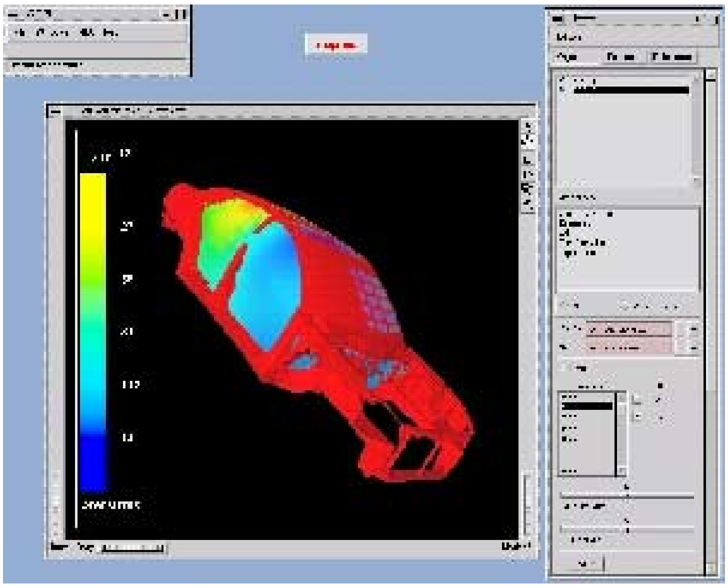

Figure 4 : *GTI6 VR framework.*

GTI6 – SEC (Security)

The GTI6 Security box is aimed at encrypting and decrypting the exchanged data according to the strongest security requirements. It can be simply performed at IP level by an Ethernet Black Box or by more complex mechanisms of authentication and secured access. This box should only be used when really needed as generally impacting bandwidth and latency

GTI6 – SRG (Surrogate)

One of the challenges of GTI6 is to support the geographical distribution of simulation facilities in closed loop and in real time with real Hardware in the Loop. One of the key concept to implement this geographical distribution is the GTI6 surrogate that:

- replaces locally a remote hardware equipment,
- communicates with this remote component,
- respects exactly the same HW and SW interface and behaves exactly as would do the replaced component,

– gives to the simulator or to the engineer the impression he communicates directly with the other one(s), as in a centralised manner, by compensating possible perturbations involved by the distribution.

So, the purpose of a surrogate is to give to a local node exactly the same capabilities as those of the centralised simulation, by hiding the distribution.

GTI6 – SIM (Simulation Framework)

The Simulation Framework is the infrastructure supporting and scheduling the models execution, either in real-time or faster than real-time. Commercial simulation frameworks such as Eurosim (Fokker Space) or SRDS (D3) can be simply plugged to GTI6 as the only constraint for these frameworks is to be HLA-compliant, that means to respect the HLA interface specifications.

Applications and results

Two applications have already been integrated and evaluated with a GTI6 precursor (EDISON):

1. Distributed validation of a spacecraft:

A GTI6 precursor (EDISON) was integrated and qualified for the distributed validation of a spacecraft, in hard real-time and with real hardware in the loop.

2. Space mission rehearsal and training:

The same GTI6 precursor was qualified with another space application, related to the training of distant teams on a common simulation exercise.

Other applications are currently under integration or will be soon integrated with the industrialised version of GTI6:

3. Remote support to the Arian 5 EAP control team:

EAP stands for "Etage d'Acceleration à Poudres" and are the two lateral boosters of Ariane 5. Here, the purpose is to accelerate the control process of the Ariane 5 EAP control. The EAP are built and controlled in Kourou (French Guyana) while the experts are in Les Mureaux near Paris. It is an operational application of GTI6.

4. Distributed System Engineering:

The GTI6 will also be used to serve a distributed process of design and review of a spacecraft. This will make this process faster and more flexible, as the engineering team will better and more regularly collaborate through the network thanks to efficient Groupware and Application Sharing tools.

Each of these applications partially used the modular GTI6 package, with the following coverage:

components / applications	NW	SEC	SPV	SYN	MW	GW	SIM	VR	SRG
1. Validation	✓		✓	✓	✓	✓			✓
2. Training	✓		✓	✓	✓	✓	✓	✓	✓
3. Control	✓	✓	✓			✓			✓
4. Engineering	✓		✓			✓			

Only the results of the first two applications are today available and presented hereafter.

Distributed validation of a spacecraft

PRINCIPLE:

A precursor project of GTI6 was EDISON (European Distributed Interactive Simulation Over Network, ref. [1]). It was a European R&D project (Esprit 26347) aimed at developing and evaluating a generic kernel for distributed simulation. One pilot application was then selected to qualify this kernel through a test case including real hardware equipment in a real-time loop. The chosen case for this pilot application was to connect two simulation facilities related to the validation of the rendezvous and docking of the

Automated Transfer Vehicle (ATV) to the International Space Station (ISS). The ATV is a spacecraft which docks automatically to the International Space Station in order to refuel, resupply and reboost it.

One of the simulation facility is representative of the future *ATV Functional Simulation Facility* (ATV FSF) that will be installed in 2001 in Les Mureaux at the EADS LV premises near Paris. The second simulation facility is the *European Proximity Operations Simulator* (EPOS) installed at DLR near Munich. This facility comprises a gantry robot carrying a 6 Degrees of Freedom (DoF) moving table that simulates the dynamic behaviour of the ATV, on which the ATV Rendez-Vous Sensor (RVS) is mounted. On another fixed 3-DoF table the ISS laser reflectors are mounted. The control/command of the EPOS robotic systems allows the user to reproduce the relative position, attitude and velocities of the 2 space vehicles during the last 10 meters of their rendezvous manoeuvre.

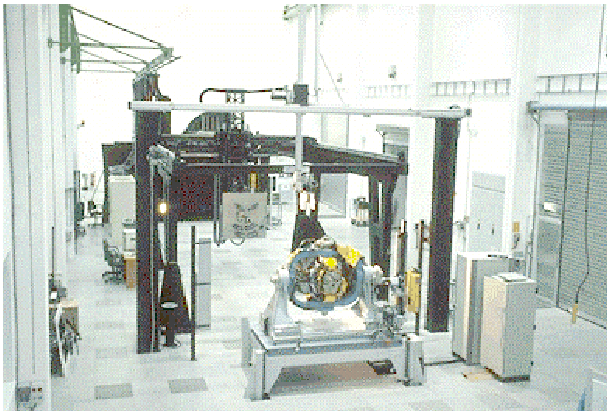

Figure 5 : *EPOS with the RendezVous sensor (RVS)*

In order to reach the highest level of fidelity for the entire system validation, it has been envisaged to connect the ATV FSF to EPOS and make them interoperate in a closed loop. The optical RVS mounted on EPOS in Germany shall run, in real time, on a common simulation with the ATV Fault Tolerant Computer (FTC) and other sub-components of the ATV system located on the ATV FSF in France.

A remote link between these facilities would avoid the necessity of transportation or duplication of one of them. The distributed architecture must then be as valid as if both simulation facilities would be present in the same location. The geographical distribution basically cuts the close-loop simulation and consequently introduces additional delays and possible errors. It is essential to minimise these errors down to a certain limit, in order to get the same ATV trajectory and behaviour as the one we would get in a unique centralised test facility.

DISTRIBUTED SIMULATION CLOSE LOOP:

The closed-loop simulation for the validation of the rendez-vous and docking scenario consists of following 7 steps described in Table hereafter:

#	Location	Description
1	FTC	The FTC performs all Guidance, Navigation & Control (GNC) calculations and computes the thrusters commands at 10Hz.
2	1553 data	These commands are sent at 10Hz to the Propulsion Drive Electronics (PDE) and are monitored on the 1553 bus of the FSF.
3	FSF	The FSF computes the ATV trajectory and prepares the resulting EPOS commands.
4	Ethernet data	The EPOS commands are sent to EPOS at 2Hz according to the Ethernet TCP/IP client / server protocol of EPOS.
5	EPOS	EPOS performs its motion simulating the ATV-ISS dynamics, and generates optical conditions for the RVS.
6	RVS	The RVS moves with EPOS, it records the ISS target pattern and computes the relative position, attitude and velocities.
7	1553 data	The RVS sends at 2Hz its measurements to the FTC via the 1553 bus, as new GNC inputs.

The goal of this application is to cut the steps 4 and 7 and to distribute the associated data through the WAN (command messages sent to EPOS in one way, and RVS measurements sent to the FSF on the way back), as illustrated by the following diagram:

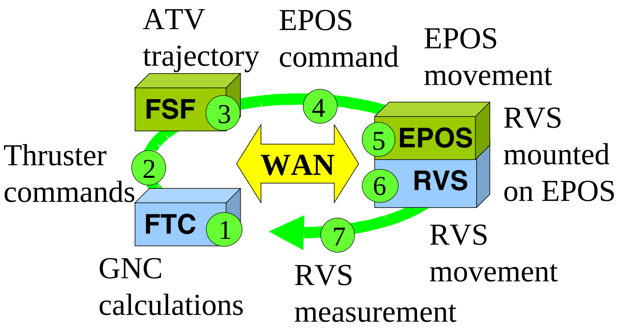

***Figure 6 :** ATV closed loop simulation*

The network topology used for the experimentation was an ATM 2Mbps Private Network between EADS LV in France and DLR in Germany, configured with CBR Quality of Service (Constant Bit Rate). The challenge here was to mix several heterogeneous dataflows on the same network (simulation, supervision and groupware data).

RESULTS

Six high level criteria were defined to qualify the precursor GTI6 kernel with this pilot application:

- The **latency** induced by the distribution should be less then 50ms to respect the real-time constraints of the ATV,
- The **synchronisation** between the distant sites should be at least 1 ms,
- The distributed system should have the same level of **fidelity** as if it were a centralized facility in a same location.
- The kernel **reliability** should be 100%
- The kernel **availability** should be 100%
- The kernel **useability** should be sufficient to allow the set up and the execution of a new distributed simulation exercise in less than 5 minutes.

All the required performances were verified by tests. In particular, the kernel was **fully available, reliable and easy to use**. The average round trip time provided by ‘ping’ tests was 40 ms, which gives about 20 ms one way between France and Germany. The latency was then measured at the Middleware level with an average value of 28ms, and at Surrogate level with 52 ms. In the local mode, the latency was measured at 6ms. That means the **kernel overall latency was 46ms**, so less than the specified 50ms.

All the different platforms running simulation federates have been synchronised using the GTI6-SYNC box. The achieved synchronisation was better than 1 millisecond between SGI workstations, and around 10 milliseconds on PC NT. The accuracy of the synchronisation is critical in this distributed application, as the synchronisation of the loop must not be affected by the distribution.

Moreover, a maximum difference of 0.1mm has been measured between trajectories obtained in local and in distributed mode. This is definitely a very high accuracy demonstrating that the geographical distribution does not impact the simulation fidelity.

In conclusion, from a technical point of view, this experiment demonstrated the capability and feasibility of this GTI6 precursor to support distributed simulation exercises with hard real-time constraints and with hardware in the loop.

Space mission rehearsal and training

PRINCIPLE

In the EDISON project, this application aimed at demonstrating that the GTI6 precursor kernel allows to organise mission rehearsal and operator training operations without long collocation of ground operators, ISS crew members and training personnel. In the simulation/training scenario selected as a baseline, it is assumed that the ATV initially has a problem with deployment of one of its solar arrays (panels). To investigate how serious is the problem, and if RendezVous & Docking (RVD) can be accomplished nominally, the failed panel and elements around it should be examined by means of a TV-camera. However, a body-fixed ISS camera to be used to monitor ATV RVD in nominal conditions is not sufficient for this purpose because its field of view is aligned with the approach line. Thus, the ATV panels, if not deployed nominally, may be not visible enough in this case. It is assumed that a TV-camera mounted on the ISS European Robotic Arm (ERA) manipulator could be used for investigating the problem. For example, as soon as the ATV is close enough to the ISS, its approach will be stopped, ERA deployed with one of its cameras pointing the spacecraft. The latter, in turn, could be controlled so that to ensure appropriate visibility conditions for the crew and ground controllers. Therefore, the scenario implies cooperative control of ATV, ISS and ERA from two control centres and the crew control post.

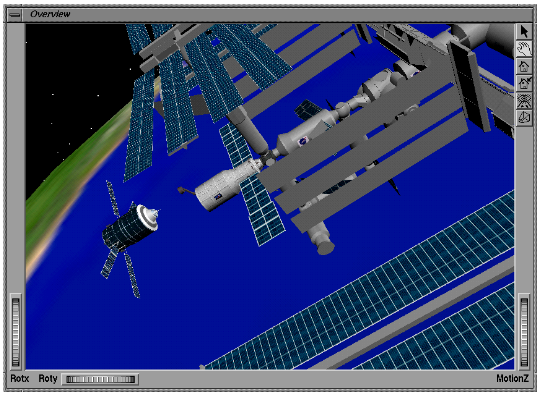

Figure 7 : *ATV docking to ISS*

DISTRIBUTED SIMULATION CLOSE LOOP

This was demonstrated by involving the following components in a common (though distributed!) training and operational environment:

- astronaut trainer on the ERA simulation facility (European Robotic Arm, located at Fokker Space - Leiden),
- ATV ground controller system on Ground Operator Assistance Subsystem (GOAS, located at Alenia Spazio - Turin) simulating the ATV Control Center (ATV-CC),
- ATV model (located at EADS LAUNCH VEHICLES - Les Mureaux),
- ISS model (running on a computer system of the University of Stuttgart - RUS centre)
- and the Mission Control Centre (MCC) simulator for ground controllers training (running in Stuttgart).

The simulation sessions of the MIL application had been performed using both ISDN and ATM WANs interconnecting distant simulation and demonstration sites within Europe, with the following characteristics:

ISDN WAN:

- Interconnection of 3 nodes (ESA/ESTEC in Noordwijk, D3 in Bonn, EADS LV in Les Mureaux)
- 64/128 Kbps bandwidth
- 30-200 ms latency (depending on site-to-site connection)
- No manageable quality of service for different data streams
- Used only for simulation data.
- ATM-based WAN:

- Interconnection of 4 nodes (EADS LV in Les Mureaux, Alenia Spazio in Turin, Fokker Space in the Netherlands, RUS in Stuttgart).
- 2 Mbps bandwidth
- 20-30 ms latency (depending on site-to-site connection)
- Manageable quality of service for different data streams
- Permanent inter-site connections
- Used both for simulation, supervision and groupware data.

RESULTS

Evaluation of the simulation results was driven by the following objectives:

- to evaluate the suitability of the HLA technology for cosmonaut and ground operator training in a distributed environment:
- individual training to monitor RVD process and intervene into it with dynamic vehicle models/simulations (ATV, ISS) running remotely
- developing team skills to jointly tackle contingencies (crew and several ground teams)
- to evaluate possibility to perform mission rehearsal when several distributed sites are involved and their correct interactions are critical for mission rehearsal.

The following issues had also to be clarified during the simulations:

- to what extent the transport delay between remote simulations impacts the human operator controlling the ATV and/or ERA ?
- could ownership transfer be provided quickly enough while switching from one control post (e.g. ground) to another (e.g. ISS crew) ?

The following three groups of test runs have been performed to address different RVD scenarios.

Scenario №1: Reference case with only initial test of manual mode.

- To make sure that manual control mode is functioning properly, the ATV-CC takes the responsibility to test it while the ATV is at the hold point some 250 m away from the ISS. Ground operator checks how the spacecraft reacts to his inputs control inputs along all 6 degrees of freedom
- After the above ATV-CC check is completed, the same test is repeated by the ISS crew
- ATV is returned to the automatic mode
- ATV Final Translation starts and goes on nominally until the docking contact.
- Runs on scenario №1 demonstrated that ATV manoeuvrability and controllability in the manual mode is acceptable. The recorded trajectories indicate that:
- ATV was manually controllable both in case when it was controlled from ground and from onboard the ISS. Latency compensation based on linear extrapolation of manual control inputs was sufficient.
- Smooth transition from automatic mode to manual and back was ensured by the ATV GNC subsystem.

Scenario №2: ATV Rendezvous Sensor failure at a distance of 15 m from the ISS:

- At about 15 meters from docking, the ATV RVS failure (assumed undetected by the ATV fault-detection subsystem) has been introduced
- The ATV-CC operators detect the failure indirectly, by using telemetry (TM) data
- ATV-CC switches ATV GNC to Manual Control Mode
- ISS crew continues approach in manual mode and docks ATV to the ISS.

Runs on scenario №2 additionally demonstrated effectiveness of cooperative work of different groups of operators:

- After the ATV RVS failure has been introduced, ground controllers had quickly detected the failure and commanded the crew about taking over the control
- ISS crew completed the approach in the manual control mode.

Scenario №3: TV link shutdown at 15 m:

- At about 15 meters from docking, a TV link shutdown has been introduced
- MCC issues a command to an ATV-CC ground operator to stop the approach by nullifying the approach velocity using only TM data and maintain station keeping in manual mode until the ISS crew takes over the control
- ATV-CC switches ATV GNC to the manual control Mode.
- ATV-CC operator controls ATV by means of TM only
- MCC issues a command to the ISS crew to take over manual control of ATV
- ISS crew resumes approach in manual mode
- ISS crew completes the docking manually.

Runs on scenario №3 additionally demonstrated effectiveness of implementation of the ownership transfer functionality between different control posts:

- After the TV-link failure has been introduced, a ground controller was able to keep the ATV in the additional hold point by only using telemetry data
- After the ATV-CC has released the control, the ISS crew took over the control and successfully completed the approach in the manual control mode.

In conclusion, these results demonstrated the suitability of this GTI6 precursor to support complex man-in-the-loop distributed simulations such as those purposed for international space programs.

Conclusions and perspectives

GTI6 has been developed by EADS LAUNCH VEHICLES as an effective environment to support large-scale applications of Distributed Interactive Simulations as well as Collaborative Engineering platforms.

Different teams can in such a way interact each other from their own location, simultaneously accessing and operating on remote applications, global data repositories or archives. These teams can also interconnect their Simulation Facilities together and make them interoperable in real-time and in close-loop in spite of the network distance. They can as well collectively create, manipulate and review documents, project data and simulation objects with the support of a concurrent multipoint groupware and work sharing system.

This is a common need in the current frame of closer and closer collaborations among the world-wide industries. GTI6 has been developed, tested and qualified in the Space industry and is now ready to improve the competitiveness of other sectors by sharing the benefits of 'distributed and interoperable systems' concept, for example with the following domains: distributed engineering of complex and innovative concepts (trains, planes, cars…), distributed training in transportation industry, telemedicine or teleoperations in hazardous situations.

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The Agent Based Simulation Opportunity

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Summary

Agent based approaches offer a tremendous opportunity to drastically enhance our ability to everything simulate everything from human behaviour to large complex computer networks. This paper examines this recent simulation paradigm and looks at how it can be applied to current military modeling and simulation (M&S) challenges. First, a foundation discussion is provided that examines the meaning of agent based simulation. Next, the paper looks at a representative sample of research of agent based simulations. The paper then concludes with a current opportunity for using agent based approaches in the verification and validation of simulations.

Introduction

The role of modeling and simulation (M&S) is changing. Historically, simulations have been applied to reasonably well understood problems, often problems that had elegant mathematical underpinnings. For example, Lanchester equations have been used successfully to describe attrition in a number of force on force models such as the Corps Battle Simulation [1]. This matched well with the primary role of the military, which was structured to fight a major war against a superpower opponent.

Things have changed significantly since the fall of the Soviet Union. Increasingly the military forces are called on to support Operations Other Than War [2] such as refugee resettlement, stability and support operations for a multi-sided conflict and disaster relief. The underlying mathematical principles that would be used to model and then simulate these situations are poorly understood, if they exist at all. However, the requirement to provide M&S tools to support decision analysis for situations such as OOTWs remains. A different approach to M&S is necessary.

Agent based approaches are an evolving technique to gain visibility into previously intractable problems. This paper will examine agent-based approaches and their potential for use. First, we will examine what is meant by agent-based simulation. Next, we will take a look at some representative agent based simulations. We will conclude with an opportunity for using agent-based approaches to address a pressing problem in modeling and simulation, the verification and validation of complex distributed simulations.

A Common Grounding

As agent technology becomes more popular and mature, the term *agent* begins to take on many meanings. Some have used the term *agent* to refer to software that uses a set of rules to sort your e-mail, while others use the term agent as a paperclip that drops down during a Microsoft Word session. Here, we will use the definition offered by Woolridge [3]. While Woolridge recognizes the wide variety of interpretations and differentiates between an agent and a rational agent, he defines agents with several distinct properties. At the lowest level, an agent is an entity that acts upon the environment that it inhabits. Of more interest is a rational agent who has the properties of autonomy, proactiveness, reactivity and social ability. For our purposes, when the term agents is used, it is will the understanding that they have all of the properties of Woolridge's rational agent.

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As a coarse grouping, agents can be broken into three categories, heavyweight, middleweight and lightweight. Heavyweight agents have complex local inference mechanisms, often as the result of extensive knowledge elicitation and engineering. For example, as discussed later in this paper, the TACAIR SOAR agents used in the Joint Semi-Automated Forces (JSAF) simulation is built upon the SOAR cognitive model. The knowledge engineering to build TACAIR SOAR created approximately 5000 production rules that realistically represent a pilot's behavior in a simulated fixed-wing aircraft. While not easily modified, TACAIR SOAR is generally considered a reasonable representation of how a pilot would act, from maneuvering to weapons employment. This approach to agent development can trace its roots to the expert systems such as MYCIN where significant work went into modeling the thought processes of a human with the goal of solving a problem.

Middleweight agents have a simpler knowledge base than do heavyweight agents. Middleweight agents seek to encode some behavior into the agent, but do not seek to explictly describe the vast majority of anticipated behaviors in a great amount of detail. Frequently, middleweight agents will make use of a shared ontology conducting inferencing. This paper will look at an example of middleweight agents in a few moments.

Lightweight agents have very simple rules, frequently numbering in the 10s or even less. The power of lightweight agents comes from the interaction of a number of agents. Realistic complex behaviors can evolve from the interactions of a number of simple agents over a number of timesteps. Lightweight agents can be viewed as an extension of cellular automata theory and complexity science. In addition, lightweight agents add proactiveness and social ability to reactivity and autonomy. The most prolific application of numerous lightweight agents has been in SWARM [4], which has been used to gain insights into such diverse fields as economics and traffic flows.

The use of agents in military M&S is promising from both a software engineering perspective as well as from an analysis perspective. Agents have inherent knowledge encapsulation, promoting reuse and composability. Frameworks such as the Foundation for the Interconnectivity of Physical Agents Agent Communication Language (FIPA ACL) can provide a communication architecture, both from a syntactic as well as a semantic framework [5]. A previous paper [6] examined how an agent architecture can facilitate dynamically plugging in agents into running simulations. Ongoing work at the Defense Advanced Research Projects Agency (DARPA) in the semantic web and the DARPA Agent Markup Language (DAML) will provide additional capability by allowing the dynamic reuse of ontologies between agents [7].

Research Directions

There are a multitude of agent architectures and efforts ongoing. This section briefly examines three research efforts using agents. The Project Albert is the first, it uses lightweight agents to examine a number of areas that have proven tough to model using traditional first principle approaches. The second effort looks at using middleweight agents to model various emergent behavior in crowds. Lastly, the use of heavy weight agents to model the actions of tactical aircraft pilots using TACAIR SOAR is examined.

PROJECT ALBERT

From an analysis perspective, employing lightweight agents has recently been gaining momentum in the Department of Defense, such as Project Albert [8]. One of the more intriguing aspects of lightweight agent approaches is that the modeler does not need a detailed understanding on the global phenomena, only of the relevant local behaviors for each individual agent. By observing the aggregate behavior of the simulation, insights can be made about the underlying principals behind the simulation. In the ideal, lightweight agents can be used to develop mathematically based first principle models. It is important to point out that these lightweight simulations usually have a significant amount of randomness embedded during their construction. Thus, point observations from a small number of simulation runs will give a non-representative view of the aggregate behavior. Project Albert has adopted the approach of varying the parameters over hundreds or even thousands of input runs to gain visibility into the underlying relationships and behaviors. Current research includes using lightweight agent simulations to examine aspects of Control Operations, Optimal Force Mix, Precision Maneuver, Mission Area Analysis and Peace Support Operations.

The genesis of Project Albert came from a perceived weakness in the current approach to modeling and simulating complex phenomena. In particular, Project Albert is attempting to address four key shortcomings of traditional M&S:

- **Non-linear Behavior**. These are situations where a small change in the model baseline (and the real world) creates a disproportionate response. These areas of non-linear behavior may be equated to opportunities and weaknesses within a military operation.

- **Co-evolving Landscapes.** The battlefield is fluid and dynamic as each commander adjusts his plan to the changing circumstances of the battle. Co-evolving landscapes attempt to account for the "I think he thinks" situation in a modeling and simulation process.

- **Intangibles.** Intangible factors, also known as moderating factors, include considerations within the M&S such as fatigue, morale, discipline, and training. These factors have an enormous, but traditionally unaccounted for, outcome on battles. Project Albert uses personality-based models to investigate these issues.

- **Data Management.** Project Albert uses two data management concepts to assist in identifying areas of interest. This is accomplished by allowing users to investigate large amounts of data in order to identify situations where data relationships become non-linear or produce other "interesting" results. These concepts are:

  - *Data Farming***.** Data farming involves the investigation of a wide number of variables, across a wide range of values. In essence, the user is attempting to model all possible combinations and variations within the data space. Data farming is reliant on a series of simple but reliable models that have been developed specifically for Project Albert, and the use of high performance computing assets.

  - *Data Mining***.** Data mining involves the sorting and filtering of the data farming output to identify combinations of variables that generate non-linear or interesting situations. The current suite of data mining tools includes a mixture of manual COTS and Project Albert applications.

The current Project Albert models include simulation frameworks such as ISAAC, Einstein, Archimedes, Socrates, and Mana. All of these models fall into the category of "agent-based models." ISAAC and Einstein were two of the earliest agent-based models that were developed by the Center for Naval Analysis (CNA) to investigate the potential of agent-based models for replicating combat. Archimedes uses neural networks and fuzzy logic to represent decision-making and other intangible factors and was developed within Project Albert. Socrates, developed jointly by DMSO and Project Albert, is similar to Archimedes in concept, but uses value-driven decision logic to represent decision-making and other intangible factors. Mana was developed by the Defence Technology Agency of the New Zealand Defence Force and uses a situation awareness "map" that provides for global interactions and events that can trigger changes in agent personalities.

MODELING CROWD BEHAVIOR – AN APPLICATION OF MIDDLEWEIGHT AGENTS

Silverman [9] and his colleagues at the University of Pennsylvania in the United States are researching the use of agents to model emergent crowd behavior. Their approach integrates human behavior models of ability, stress, emotion, decision-making, and motivation into a game-theoretic framework. In a similar vein of Project Albert, they seek to create a simulation environment that allows research and exploration of alternative human behavior models. The model takes into account cultural perspectives as well as reaction times and perspective based cognition. Silverman develops a common mathematical framework around a dynamical, game-theoretic approach to evolution and equilibrium in Markov chains representing states of the world that the agents can act upon. In these worlds the agents' assess relative actions against perceive payoffs, which are derived by a deep model of cognitive appraisal of intention achievement including assessment of emotional activation/decay relative to concern ontologies. Further, the payoff assessment is subject to stress and related constraints.

This work is interesting from a number of perspectives. First, Silverman has made good use of the literature in improving the realism of behavior models. Silverman's model employs game theory and the belief desire intention (BDI) models to good use. In fact, some of the appeal of this approach is that it integrates a number of models into a common framework based on Markov chains and utility theory.

This is important because there currently is no single validated theory of human behavior, nor is there a validated theory for the integration of various models. Silverman has instantiated his model in a prototype system to observe how various actors will react in potentially violent crowd situation. The actors are modeled as agents, whose utility calculations are directly influenced by their perceived context as well their emotional state. Contingent upon the context and “tipping points”, the agents may migrate to mob behavior against the perceived authorities.

The initial results indicate that emotion models are useful for utility and decision making not just for expressivity. By using ontology derived emotion that is dynamically calculated, the effect on perceived payoffs for differing choices can be readily simulated. This differs from the traditional decision theoretic approaches that do not provide local calculations for utilities, but instead calculate them in an a priori sense using elicitation from a subject matter expert. Thus, knowledge elicitation for emotional preferences is conducted with the subject matter expert to derive the working ontology, but agents calculate instance specific utilities on the fly.

TACAIR SOAR – A HEAVYWEIGHT AGENT EXAMPLE

TACAIR SOAR [10] is a heavyweight agent designed to provide believable behavior for simulated pilots in large scale distributed military simulations. Development of TACAIR SOAR began in 1992 at the University of Michigan by John Laird, and Paul Rosenbloom. TACAIR SOAR is based upon the SOAR Computational Architecture, a cognitive model which provides goal-directed behavior, a learning methodology and planning. The heart of TACAIR SOAR resides in its extensive knowledge base consisting of over five thousand (5000) production rules. TACAIR SOAR Agents can mimic hierarchical control and interface with human operators in a fixed vocabulary. In fact, TACAIR SOAR is capable of simulating most of the airborne missions that the Department of Defense flies in fixed-wing aircraft. TACAIR SOAR is currently deployed at Naval Air Station (NAS) Oceana, Virginia, and the Air Force Research Laboratory (AFRL) Human Effectiveness Research Site in Mesa, Arizona.

The desired TACAIR SOAR goal is to generate behavior that “looks human”, when viewed by a training audience participating in operational military exercises. The first extensive use of TACAIR SOAR was during the Synthetic Theater Of War 1997 (STOW 97) exercise held 29-31 Oct 1997. In STOW 97 TACAIR SOAR agents flew 722 individual sorties piloting simulated U.S. fixed-wing aircraft. TACAIR SOAR agents successfully flew over 95% of the sorties. The following year, TACAIR SOAR participated in the USAF exercise “RoadRunner 98”. In “RoadRunner 98” TACAIR SOAR flew simulated aircraft both with and against human pilots in virtual simulations. In both exercises, the flight behavior provided by the agents was judged as “reasonable”. In other words, a human pilot may not have performed a given maneuver in a specific context, but the maneuver or action chosen by the agent was believable.

TACAIR SOAR is continues to evolve. SOAR, which began as a university research effort has matured into a commercial architecture upon which TACAIR SOAR is built. SOAR Technology, the commercial venture has built SOAR Speak to allow a natural language interface with SOAR agents. The agents work on a restricted vocabulary, which is closely matched to the vocabulary of human pilots. The implementation of a natural language interface enhances the training realism.

An Opportunity for Agents in Verification and Validation

In the previous section, the use of agents to model human behavior in constructive simulations was examined. The agent simulations used within Project Albert seek insights into the best way to employ forces and evolve tactics. Silverman’s investigation provides some indication regarding how a relatively straightforward utility model can incorporate emotions to derive more realistic behaviors. TACAIR SOAR models simulated pilots in such a realistic fashion that real pilots in a virtual simulator can “fly” with them and consider their behavior reasonable. However, using agents in this fashion is only one aspect of how the technology can be employed. In this section we examine using an agent approach to ensure that complex simulations are performing correctly.

Verification and Validation (V&V) continues to be one of the more vexing challenges in M&S [11]. Ensuring that simulations perform as designed and that the execution is appropriate for the context becomes increasingly difficult as the number of simulated entities with local behaviors exceeds 104 and begins to approach 105, as is the intention in the soon to be employed Joint Simulation System (JSIMS).

The Defense Modeling and Simulation Office (DMSO) developed a Verification and Validation (V&V) Recommended Practices Guide (RPG) (http://www.msiac.dmso.mil/vva/) in cooperation with many collaborators from industry and academia. The RPG provides guidance and suggested successful practices to employ in the V&V of M&S. However, even with codified practices, the complexity of large simulations still makes adequate V&V a significant challenge.

The foundation of V&V is based upon a solid requirements definition. Specification of the functionality of the model or simulation is usually done informally (such as text based descriptions), formally (e.g., logic-based specification) or semi-formally (e.g., the Unified Modeling Language [UML]) and drives the creation of test cases as well as operational scenarios. V&V can be viewed as the systematic interpretation and translation of these requirements into test cases, running of the test cases, and the accumulation of evidence provided by these test cases that the system will behave as designed and in an appropriate fashion for the operational context.

For rational agents to assist in the V&V of a system there must be some way to translate the specifications into a lingua franca that is both syntactically and semantically understandable for the agents, as well as to provide a foundation for the agents to communicate with each other. As previously mentioned, the syntactic understanding of messages can be greatly assisted by using a framework such as FIPA. However, for the significant understanding that would allow reasoning about both the specifications as well as the results of the test cases, an ontology capturing the concepts of V&V and system specification is necessary. Several researchers have developed ontologies for software engineering. However, to date an agreed upon generic V&V ontology or work that maps this back to a generic modeling and simulation ontology has not surfaced. However, the basis for an ontology such as this has been developed in the RPG. The RPG relates V&V concepts in a many-to-many relationship and can be navigated through a browser. While work remains to be done to translate this largely text-based knowledge base into full-fledged ontology, the foundation has been completed and is undergoing active maintenance.

On a slightly broader note, using agents to for the development of ontologies is an active area of research. Steels [12] discusses the complexities of using top-down methodologies to create a shared ontology. Specifically, he cites several reasons:

- It is hard to imagine how there could ever be a worldwide consensus about the ontologies and associated languages for every possible domain of multi-agent application.
- Multi-agent systems are typically open systems. This means that the conventions cannot be defined once and for all but are expected to expand as new needs arise.
- Multi-agent systems are typically distributed systems. There is not central control point. This raises the issue how evolving communication conventions might spread to agents that are already operational.

Steels advocates using agents to evolve a shared ontology from a complex adaptive systems perspective. The formation of the ontology arises from local interactions over a large number of iterations.

Assuming that there was such a unified ontology could be created, how would one employ it to conduct V&V on a model? Research is currently underway that highlights how one can translate semi-formal specifications into more formal representations. For example, previous work by the author [13] demonstrated an approach for translating Use-Case Diagrams and Collaboration Diagrams into Bayesian Network representations of system requirements. In an independent research effort, Saldhana [14] demonstrated the translation of modeling UML Diagrams as Object Petri Nets. From these two efforts, one can envision that the mapping of the specifications to test cases and the real-time interpretation of these test cases as they are run can be assisted by agents. Consider the following scenario. A simulation is created that will explore the effect of a radar jammer installed on an aircraft. A test case is developed that will “fly” the simulated aircraft over cyber-terrain and illuminate the aircraft with the simulated radar. The aircraft will then turn on its jammer. Now, suppose that the simulation contained agents that can interpret the behavior of the various entities. The knowledge base of the agents was instantiated by the simulation specifications. The agents could then compare the simulation behavior to the test cases and assertions could be made as to which of the test cases were validated, partially validated or failed validation predicated on the test results as they unfold.

The use of a number of agents monitoring the simulation as it runs is particularly appealing in complex situations because verifying the behavior of a given situation against all possible execution paths is often “NP Hard”. However, consider the use of monitoring agents that track the execution of the simulation, continuously interpreting various results against the specifications. It is possible to see a future where the V&V of a simulation becomes a continuous process, with the importance of developing specified tests reduced in favor of exercising the system. V&V can then be viewed as the accumulation of evidence that the system will function as intended. By continuously monitoring system performance and comparing performance against the system specifications we can begin to develop that argument.

This said, what are the component pieces necessary to support an agent approach for V&V? First, a representative specification of both the technical characteristics (Verification) and the operational characteristics (Validation) is essential. The specification must then be translated into something that the agent can reason about. Second, indicators within the simulation must be identified and mapped to these specifications that will allow an agent or agents to infer with respect to the specification whether the behavior of the simulation is appropriate. Third, a reasoning engine must be able to develop real-time conclusions and reassess the conclusions over time. Fourth, it would be desirable for the agents to be trainable and possess learning methodologies.

The V&V problem can be viewed as an exercise in uncertain reasoning. Given that there is a true user need, a translation exercise occurs to document that user need as a user requirement. This can be represented as simple equations using Bayes rule. Let the actual need be represented by N, the probability that the user requirement U sufficiently documents N can be represented by P(U|N). Therefore, P(U|N) = P(N) * P(N|U)/ P(U). Similarly, there is a degree of uncertainty that the system requirements S that is defined for a user requirement U actually represents that requirement. In other words, P(S|U) = P(U) * P(S|U)/P(S). Continuing, there is a degree of uncertainty that the test case T actually represents the system requirement T. As before, P(T|S) = P(S)*P(S|T)/P(T).

By chaining these equations, one can represent the probability that the test case developed does in fact actually test if the user requirement is met. To do this it is necessary to define a new distribution that is dependent upon the introduction of evidence. Given the probability that the test case adequately represents N, and the introduction of evidence, what is the probability that the user need is met. One can introduce Ts to represent the probability that user need is met. Thus, the objective is to determine P(Ts|T, A, B, C, …n) where A, B, C….n are evidence variables.

As one can see, it becomes somewhat cumbersome to specify all the relevant equations. Graphical techniques have proven useful in reducing the computational burden and increasing understanding of the problem space and interrelationships between variables. In particular, a number of commercial products have implemented Bayesian networks which provide the framework to develop an quantitative networked model of variables in a problem space based upon Bayes rule. The Bayesian networks can be used to actively model effects of the introduction of evidence. For a good introductory discussion of Bayesian networks consider Jensen [15].

As an example of how this might work, consider the situation where agents are employed to continually monitor the state of the evidence variables, which change their values over time. By examining the time phased probability distribution, one can draw conclusions about both how well the technical specifications are met as well as how well this relates to the user need being met. Further and perhaps even more powerfully, one can conduct continuous evaluation, both during the official Test and Evaluation phase of the system, as well as during system operation.

In many cases Validation purely by specification is impossible. The sheer complexity of the specifications to accurately describe the behavior of the simulation in even the most common uses would be overwhelming. It is suggested that an agent-based approach would provide utility here as well. In particular, one can develop the inference mechanism of the agent to attempt to mimic an expert. In other words, we can create a knowledge base that looks for atypical behaviors for the simulation based upon contextual information and other factors that an expert would bring to the validation exercise. As before, the agent will look for indicators of atypical behavior and report its hypothesis of a problem or problem to the user. The validation is continual; similar to a computer chip that monitors engine performance.

When this approach has been described to colleagues, there have been two primary objections. First, a system composed of a number of agents will require significant computational resources that will likely

degrade performance. Due to the continuos and rapid advances in hardware, this is considered a minor issue. Moore's Law has demonstrated the speed of processors is doubling every eighteen months. Further, the ability to distribute the agents and their associated computation also contributes to making this a relatively minor challenge. Certainly the insatiable desire forever increasing computational will continue, but at some point the incredible value of the V&V agents will mandate their incorporation or application.

The second objection focuses on the use of Bayesian networks. Some believe it is too hard to assess the large number of conditional and prior probabilities necessary for a reasonably complex Bayesian Network. Previous work [16] has demonstrated that heuristic rules are often effective in assessing conditional and prior probabilities, with the associated structure being much more important. Further, the development of simple knowledge bases such as production rule systems to interpret and incoming evidence and alter underlying Bayesian networks has also been demonstrated.

Conclusions

This paper has provided a background on agent technology as applied to some potential applications in modelling and simulations. First, a discussion focused on a terminological backdrop for exploring agent research. Then, three examples were examined, each of which represented one of the three types of agents introduced. All of the examples focused on representing some aspect of human behavior. Lastly, the paper switched gears and introduced a non-traditional use of agents to verify and validate complex simulations.

It was deliberate that the paper provided only a brief glimpse into the many ongoing agent efforts, as the number of uses of this computational paradigm is increasing daily and there are a number of good survey papers (e.g., [17] and [18]). What the paper tried to do was provide a lens by which to view other ongoing works. The approach suggested in the last section is one that employs heavyweight agents, as a significant amount of knowledge engineering in necessary to enable the agents to understand how the simulation execution relates to the defined specifications.

It should be pointed out that agent approaches are not necessarily orthogonal to traditional modelling and simulation techniques, but may in fact be complimentary as was suggested in the previous section. Agent based approaches are becoming increasingly important to tackle some of the more challenging problems in all facets of modelling and simulation. It is becoming increasingly evident that the use of agents in M&S will continue to grow, in more established venues as human behavior representation as well as in non-traditional roles such as V&V.

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14. Abstract

The conference presented a series of papers in sessions that were designed to provide an overview of NATO and national M&S Organisations, Perspectives, Projects, Practices and Policy. Other topics covered were the use of M&S to support operations (e.g. training and communication systems), future trends in M&S (such as Virtual Forces and Artificial Intelligence, Gaming and Agent Technology, etc.), M&S best practices (such as Validation Verification & Accreditation (VV&A) and standards).

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